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HAWAII AGRICULTURAL EXPERIMENT STATION
HONOLULU, HAWAII
Under the joint supervision of the
UNITED STATES DEPARTMENT OF AGRICULTURE
AND THE UNIVERSITY OF HAWAII

BULLETIN No. 62

PHYSICAL PROPERTIES OF HAWAII SOILS

WITH SPECIAL REFERENCE TO THE COLLOIDAL FRACTION

BY

CHARLES RICHTER, Assistant Chemist

U.S. DEPOSITORY

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INTRODUCTION

The origin, formation, and composition of tropical Hawaii soils invest them with physical and chemical properties which vary widely and are quite unlike those of the soils of the mainland of the United States. In some cases they also differ considerably from those of soils of other tropical countries.

The large amounts of fine material, organic and inorganic, with a chemical composition typical of lateritic decomposition, cause conditions which are radically different from those of other soils and which are sometimes extreme in nature. Moisture relationships especially exhibit unusual behavior in many of the soils.

It has long been known that the colloidal fraction of the soil plays a significant rôle in the soil complex phenomena. The investigations of the past decade have definitely established the fact that practically all the essential properties of soils are directly or indirectly linked with the colloidal phase, and that such important processes as flocculation, drainage, plasticity, moisture-holding capacity, shrinkage, fixation and availability of plant-food elements, hydrogen-ion concentration, and base exchange are functions of the colloidal part of the soil.

The soils of Hawaii, because of the above-mentioned differences in origin, formation, and composition, may be logically expected to exhibit a difference in the nature of the colloidal complex as compared with soils of other countries.

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SOME FACTS RELATIVE TO TROPICAL SOIL FORMATION

The soils of the Hawaiian Islands are almost entirely decomposition products of basaltic lava or volcanic ash under more or less humid tropical conditions. Only to a very limited extent in areas near the seashore at or near sea level is the modifying effect of limestone in the form of coral beds noticeable in soils adapted to agricul-

FIGURE 1.—Undecomposed lava flow (a–a formation)

FIGURE 2.—Field of volcanic ash showing the end of a recent lava flow (pahoehoe formation)

ture. Both the nature of the original parent material peculiar to volcanic countries and the soil-formation processes typical of tropical or subtropical latitudes are responsible for the particular types of soil formed.

Kelley and his coworkers (*21*)[1] and McGeorge (*24*), in former publications of the station, give information at some length con-

[1] Italic numbers in parentheses refer to Literature Cited, p. 41.

cerning the origin, composition, and nature of the original parent material. It is sufficient here to mention that the original lava consists chiefly of aluminous amphiboles of the darker varieties, such as hornblende (silica, 40 to 51 per cent; magnesium, 10 to 23 per cent; calcium, 10 to 13 per cent; aluminum, 6 to 14 per cent; and iron, 12 to 20 per cent), aluminous pyroxenes such as augite and leucagite (silica, 49 to 52 per cent; magnesium, 13 to 18 per cent; calcium, 22 to 24 per cent; aluminum, 6 to 7 per cent; and iron, 0.5 to 8 per cent), soda-lime feldspars (silica, 62 per cent; calcium, 5 per cent; aluminum, 24 per cent; and sodium, 9 per cent), and small amounts of magnetite (ferric oxide, 69 per cent, and ferrous oxide, 31 per cent). The chemical composition of these minerals shows that they are highly ferruginous and contain considerable amounts of calcium and magnesium. The parent materials from different localities show marked similarity in chemical composition, and they differ little in this respect from volcanic basalts of the mainland. Cross (*13*, *pp. 62*, *78*) shows that the analogues of Hawaii magmas are widely distributed over the world and that "the analogues have been chosen on the basis of similarity in norms." In their physical and morphological characteristics they show conspicuous variations giving rise, among others, to the well-known lava types of a–a and pahoehoe. (Figs. 1, 2, and 3.)

FIGURE 3.—Undecomposed lava (pahoehoe formation) showing scant vegetation

While the chemical composition of the original parent lava is responsible to a certain extent for the composition of the resultant soil, weathering processes, often referred to as "laterization," play the principal rôle. Most of the known weathering agencies enter into soil formation to a greater or less degree, but the more important are temperature, rainfall, and humidity of the atmosphere. Under tropical temperatures decomposition and oxidation of the mineral constituents are rapid, and water which is present in very large amounts is constantly exerting its hydrolizing and solvent action. As a result, the basic elements, through action of the dissolved carbonic dioxide in water, are leached out as carbonates and bicarbonates. The alkaline carbonates also react with the silica, forming soluble alkali silicates which are leached out. Consequently, of the remaining constituents, the sesquioxides of iron and alumina dominate the mineral part of the soil. The resulting soils are usually heavy in character, the clay fraction consisting of hydrated oxides of iron and alumina and double silicates of iron and alumina.

This process of soil formation is often referred to as laterization and the product designated as laterite. This latter term, which has been applied to a certain more or less well-defined tropical soil type and is constantly used in pedology, has not so far been given an exact definition, although several proposals concerning it have been made. It was first used in connection with certain porous tropical red clays, notably in India, which upon drying became hard and refractory and were used for making bricks for building purposes. Later on, the definition of the term was concerned chiefly with the processes of formation. Campbell (*11*, *pp. 120–128*) separates the processes of tropical rock decomposition into two groups—alteration and weathering—depending on the state of saturation by water of the decomposing rock material. Attempts have been made to define laterites on the basis of chemical composition. Fermor (*18*, *pp. 559–566*) proposes that the term "laterite" be restricted to soils containing 90 to 100 per cent lateritic constituents (oxides of iron, aluminum, titanium, and manganese more or less hydrated); that soils containing 50 to 90 per cent lateritic constituents be called "siliceous laterites"; that those containing 25 to 50 per cent of these constituents be called "lateritic soil"; and that soils having less than 25 per cent receive no designation on this basis. Recently, Martin and Doyne (*25*, *p. 546*) proposed that the classification of laterite and lateritic soils be made on the basis of the composition of the clay fraction. They suggest that soils of which the silica-alumina ratio in the clay fraction falls below 2 be called lateritic and that when this ratio falls below 1.33 the soil be described as laterite.

It should not be inferred from the foregoing that all the soils of Hawaii are of the same average composition and exhibit similar physical characteristics. Even though the parent material from different sources exhibits marked similarity in composition, differences in age and variations in weathering agencies are so large as to bring about a wide variety of decomposition products. Temperature changes may range from tropical heat to that approaching Temperate Zone conditions, and rainfall may vary from a few inches to several hundred inches a year. Examination of the Appendix (p. 43), giving certain climatic conditions and corresponding soils with some of their physical and chemical properties, show that the soil types of the Hawaiian Islands vary widely. Kelley and his coworkers (*21*) and McGeorge (*24*) show that soil types exist in Hawaii which are not laterites nor even lateritic in any of the senses mentioned above. The soils of Hawaii in large part may, however, be classified as laterites or lateritic.

Organic matter modifies the soil complex to no small degree and varies considerably both as to amount and state of decomposition. In very humid regions where the organic material decomposes under partly anaerobic conditions, the rate of decomposition is slow and there is likely to be an accumulation of partly decomposed organic matter. In this case large amounts of organic matter are present not only in the clay or colloidal fraction, but in the different textural subdivisions of the silt fractions as well. In the less humid areas, or where excess moisture is rapidly removed by good drainage, the organic matter is present in smaller amounts and decomposition is more thorough. From a biological point of view there

is considerable variation in the efficiency of the bacterial action bringing about decomposition. Burgess (*10, p. 32*) states that "other conditions being equal, bacterial efficiency decreases as the altitude increases," especially in so far as the ammonifiers are concerned.

Table 1 gives a comparison of the chemical composition of average mainland and Hawaii soils, and the specific gravities of the chief constituents of these soils.

TABLE 1.—*Comparison of the chemical composition of average mainland and Hawaii soils, and the specific gravities of their chief constituents*

Constituent	Mainland soils [1]	Hawaii soils [2]	Specific gravity	Constituent	Mainland soils [1]	Hawaii soils [2]	Specific gravity
	Per cent [3]	*Per cent* [3]			*Per cent* [3]	*Per cent* [3]	
SiO_2	75.64	25.78	2.65	MgO	0.72	0.14	3 60
Al_2O_3	11.00	34.91	3.75–4.00	K_2O	1.67	.31	2.30
Fe_2O_3	4.14	16.99	5.12–5.24	Na_2O	.73	.44	2.27
CaO	.75	.24	3.20–3.40	Organic matter	3.00–5	4.00–12	1.20–1.70

[1] ROBINSON, W. O., STEINKOENIG, L. A., and FRY, W. H. (*32, p. 7*).
[2] MCGEORGE, W. T. (*24, p. 6*).
[3] Averages.

It is realized that these figures are averages of wide variations and are at best only indicative. However, an attempt was made to make the figures as representative as possible by the inclusion of data typical of large areas. It is noticed that the silica content in Hawaii soils is only about one-third that of mainland soils. Iron and alumina in Hawaii soils comprise fully one-half of all the constituents and amount to more than three times the proportions found in the mainland soils. The basic elements in Hawaii soils amount to one-half to one-sixth those of the mainland soils. Certain of the rarer elements such as manganese and titanium are present sometimes in larger quantities in Hawaii soils. Manganese is found in certain areas, 4 to 9 per cent, and titanium is present to the extent of 2 to 4 per cent. Kelley and his coworkers (*21, p. 7*) report an instance in which the soil contains as high as 35 per cent titanium dioxide (TiO_2). The amount of organic matter in Hawaii soils is about two to three times as high as in mainland soils.

In view of these facts the soils of the Hawaiian Islands should be expected to exhibit physical characteristics different from those of soils of the mainland of the United States.

DESCRIPTION OF SOILS USED IN THE INVESTIGATION

In order to obtain the necessary material for the investigation herein reported, trips were made to various parts of the islands where typical and unusual soil types exist. The larger number of samples were obtained from localities widely differing in climate, elevation, and the like. The description and physical characteristics of these soils are given in tabulated form in the Appendix (p. 43). Selection of soil samples was based on the chemical and physical differences of the various soils, including soil reaction, percentage of organic matter, mechanical analysis, water-holding capacity, hygroscopic moisture, and color, and on geographical location, origin, and climatic condition. Of the 82 samples obtained, 7 came from Oahu, 25 from Maui, 10 from Kauai, and 40 from Ha-

waii. Thirty-five of the samples were taken from sugarcane fields, 8 from pineapple lands, 5 from coffee orchards (Kona), 9 from diversified agricultural areas, some of which were in edible canna, and 25 from localities growing only native vegetation or having barren land.[2]

The annual precipitation varies widely. From a few inches per annum in certain parts of east Maui to upwards of 200 inches on the Hilo coast of Hawaii, there is almost every gradation. At the peak of Mount Waialeale, Kauai, among the wettest spots on earth, the annual rainfall exceeds 500 inches. In contrast to the wide variation in rainfall, the temperature variation is relatively small. However, in certain districts, such as the Waimea Plateau, Hawaii, the temperature resembles temperate conditions, the mean being 65° F., whereas in certain very arid districts the annual mean temperature is around 80°. Agricultural areas extend to elevations as high as 4,000 feet. Temperature conditions are governed chiefly by elevation, humidity, and the prevailing air current.

Examination of certain physical and chemical data on the samples shows the great variety of soils that can be collected in the Hawaiian Islands; however, on the basis of mechanical analysis, most of the soils are clays and clay loams. Because of differences in age, degree of weathering and oxidation, and percentage of organic content, the soils show all gradations of color from almost pure yellow through all the different shades of brown and red to gray and black. Table 2 gives the color analysis of 21 typical and unusual soil types expressed on the basis of the proportion of four basic colors as adopted by the American Soil Survey Association.

TABLE 2.—*Basic colors in Hawaii soils* [a]

Sample No.	Soil type [b]	Depth	Proportion of basic color				Color
			White	Black	Yellow	Red	
		Inches	*Per cent*	*Per cen*	*Per cent*	*Per cent*	
2	Lanikai clay	0–10	3	55	23	19	Light brown.
6	Salt Lake Crater clay	0–12	4	72	13	11	Gray.
9	Peninsula clay loam	(c)	7	81	6	6	Light gray.
12	Olaa sandy clay loam	0–12	0	63	18	19	Light brown.
15	do	0–10	1	85	8	6	Gray.
17	Volcano sandy loam	0–12	6	81	6	9	Do.
21	Kona clay	0–12	2	59	20	19	Brown.
23	do	0–8	0	76	12	12	Grayish brown.
31	Kohala clay	0–12	0	80	9	11	Brown.
33	Waimea clay loam	0–12	0	80	10	10	Do.
37	Honokaa clay	0–12	0	69	16	15	Light brown.
42	Hakalau clay	0–12	0	66	16	18	Light yellowish brown.
48	Hamakuapoko clay	0–12	0	65	11	24	Brownish red.
49	do	12–24	0	65	11	24	Do.
56	Haiku clay	0–12	0	57	17	26	Light brown.
57	do	12–20	0	72	10	18	Brown.
65	Honokohau clay	(c)	14	41	35	10	Yellow.
66	do	(c)	0	39	15	46	Light red.
69	Lahaina clay	0–12	9	59	14	18	Light gray.
76	Kealia clay	0–4	2	81	9	8	Gray.
77	do	12–24	5	55	20	20	Brownish gray.

[a] Using the Munsell color method of measuring the percentage of the four basic colors as applied by the Hutton-Rice system. HUTTON, J. G. (chairman), REPORT OF SOIL COLOR STANDARDS COMMITTEE. Amer. Soil Survey Assoc. Rpt. Ann, Meeting 7, Bul. 8:53–56a. 1927.

[b] The word "type" here has not the same meaning as in a soil survey or soil classification. Lanikai clay, for example, simply means clay from Lanikai.

[c] Subsoil.

[2] The table contains descriptions of 78 soils only.

The classification of soils on the basis of color is significant because it gives information on the nature and degree of weathering and furnishes a clue to the probable chemical composition.

It is a well-known fact that in the soil-formation processes increase in temperature and decrease in rainfall act in a similar manner in the evolution of various soil types. According to Lang (*22, p. 336*), with increasing temperature or decreasing rainfall, the other weathering factors remaining constant, the soil types developing are black (raw humus), brown, yellow, and red, and laterites, in the order named. Usually dark soils of humid regions indicate imperfect drainage, slow oxidation of organic material, and consequently an accumulation of humus; whereas red soils and laterites are indicative of conditions favoring good oxidation. However, the original color of the parent material must not be lost sight of in these considerations.

FIGURE 4.—Type of vegetation responsible for the accumulation of organic matter in certain high elevations

Robinson and Holmes (*31, p. 25*) show that the chemical composition of the soil colloids is often indicated by their color and note that the soil and the corresponding colloid have the same color, differing only in intensity. Hence, there is a certain relationship between the color and the chemical composition of a soil. This has been observed in most instances with Hawaii soils also—gray, dark-brown, or black soils and colloids having a higher, and yellow and red soils and colloids a lower, silica-sesquioxide ratio.

For instance, in Table 9, giving the silica-sesquioxide ratio for the different fractions of some important Hawaii soil types, samples Nos. 291, 292, 428, and 474 are dark or gray organic soils, whereas Nos. 392, 448, and 547 are red, yellow, and brown, respectively.

Organic-matter content ranges from almost none in certain barren infertile soils to as much as 20 per cent in some mountain soils where, on account of high rainfall, poor drainage, and dense native vegetation existing prior to cultivation, there is an accumulation of organic material. Figure 4 shows the type of native vegetation that causes an accumulation of humus in certain mountain soils where high rainfall and slow drainage do not permit rapid oxidation of organic

material. Because of these and certain other conditions, the soil reaction also varies considerably from the acid upland kinds to the neutral and alkaline calcareous or saline kinds of lower levels.

On the basis of the preliminary analysis given in the Appendix, some 21 soils were selected for the main part of the investigation. The selection was made primarily with regard to origin, appearances, and physical characteristics, and secondarily, on the basis of agricultural adaptability. A few of the samples are not typical or representative of larger areas, but were included because they possessed some unusual property especially in so far as colloids are concerned. Of these 21 soils, 13 came from agricultural, and 8 came from nonagricultural districts. The description of the character and nature of the soils follow.

Soil No. 2 is a clay from Lanikai, windward Oahu, near the sea at sea level. It closely resembles the adobe type of soil and is alluvial in origin, the fine clayey material having been washed down from the surrounding mountain slopes. This is a very plastic and sticky light-brown sodium clay of low organic content. Vegetation does not do well in this soil on account of the deflocculated condition of the clay.

Soil No. 6 is a clay from Salt Lake Crater, Moanalua, near Honolulu, where the Twin Salt Lakes are located. Originally a lake bottom of saline nature, this area was reclaimed for agriculture by draining and covering with fertile loam from other localities. However, agriculture (sugarcane production) had to be abandoned because of the high alkalinity and high clay content of the soil. It is a very sticky and plastic gray clay of low organic content and high specific gravity.

Soil No. 9 is a clay loam from near the Pearl City Peninsula, Oahu, very near the ocean (Pearl Harbor), at sea level. This is a light gray, pulverulent light clay, of the type used in rice culture. It is black when moist on account of the large content of humus and partly decomposed organic matter accumulating under anaerobic conditions. The soil is very acid in reaction and has the lowest specific gravity on record in the station laboratory. The clay is in a perfect state of flocculation, due to the flocculating effect of the large amount of electrolytes present.

Soil No. 12 is a sandy clay loam from field 4–5, section F, in the Mountainview section of Olaa plantation, Hawaii. Residual in origin, this light-brown mountain soil of low clay content contains large amounts of undecomposed and partly decomposed organic matter existing under semianaerobic conditions. The soils of this district (Nos. 10 to 14, inclusive) are characterized by high moisture-absorbing and moisture-holding capacity. Forming under excessive rainfall where drainage is poor, these soils are always water-logged. The surface soils are dominated by a large amount of organic matter, whereas the subsoils are light-drab or light-brown mottled puttylike clays. The lava from which they have been formed, according to Burgess (*10*, *p. 58*), is at a depth of 2 to 3 feet. Some of these soils will hold four to five times their weight in water. In the station laboratory soil No. 11 had a moisture content of 411 per cent and soil No. 13 a moisture content of 500 per cent. (See also Shaw, *33*, *p. 420.*) Agricultural operations are carried on with

difficulty in this locality chiefly on account of the poor drainage conditions, which are being somewhat improved by ditching.

Soil No. 15 is a sandy clay loam from field W, section G, in the Mountainview section of Olaa plantation. It is residual in origin, having been formed from pahoehoe lava rock which is found about 12 to 18 inches below the surface and causes the soil to be very shallow. This gray (black when wet) acid soil is of high moisture-holding capacity and is very rocky and full of clinkers. Like soil No. 12, this soil, due to excessive rainfall and poor drainage, is water-logged. The sugarcane grown on it is stunted.

Soil No. 17 is a sandy loam from the fern forest along the main road to Volcano about 1 mile from Volcano House. This is a residual soil originating partly from the decomposition of volcanic ash and partly from lava immediately underlying the surface soil. The soil is only 12 to 18 inches deep and is black and high in organic matter from the decomposition of dense overgrowth. The hygroscopicity and moisture-holding capacity of the soil is low.

Soil No. 21 is a clay from field 3–I, Honaunau, Kona, Hawaii (coffee plantation). It is considered to be a typical coffee-district soil, and was recently cultivated for the first time. The soils of this district are the decomposition products of the various lava flows and ash deposits of Mauna Loa and are partly residual and partly alluvial. Soil No. 21 is a brown, well-aerated, productive type of good physical condition, containing a large amount of organic matter in a well-decomposed state.

Soil No. 23 is a clay from field 10–IV, Honaunau, Kona, Hawaii (coffee plantation). This typical coffee-district soil has been under cultivation for about 30 years. In origin and physical characteristics it is similar to soil No. 21, except that it is more granular in structure than the latter and contains clinkers. This soil is of medium productivity.

Soil No. 31 is a clay from pineapple fields located on the Kohala Mountain slopes at a medium elevation of about 750 feet. The soils of this district are brown uniform clays or clay loams of more or less neutral character and contain considerable humus. They are of good tilth and fertility. The annual rainfall in this district is low.

Soil No. 33 is a brown clay loam from an experimental edible-canna field of the station at Waimea, 4 miles east of Kamuela. This soil is typical of a large part of the Waimea plains—a rather cool, humid, and wind-swept region at an elevation of about 2,700 feet. The soil is of high organic content, fine uniform physical structure, and good productivity.

Soil No. 37 is a clay from the upper end of field 2, Honokaa plantation, about 100 feet from the main road. This light-brown acid soil is typical of the mauka (upper) fields of the upper Hamakua district. The high organic content of the soil here often causes an acid condition, which is being remedied by the application of lime. The soil is of a good capillarity and good moisture-holding capacity.

Soil No. 42 is a clay from field 8 of the Honohina section of Hakalau plantation, Hawaii. This is a light yellowish-brown surface soil of considerable plasticity from the low elevations of the Hilo coast where the annual precipitation is upward of 200 inches.

Soil No. 48 is a clay from the Haleakala substation, Makawao, Maui, on the slopes of Haleakala, at an elevation of 2,160 feet.

This is a brownish-red acid mountain soil of medium humus content, high in inorganic colloids, and low in hygroscopic and capillary moisture-holding capacity. This soil has a specific gravity of 3.36—the highest on record at the station laboratory. The soil has been under cultivation for some time, having been planted with diversified crops.

Soil No. 49 is a clay and the subsoil of soil No. 48, taken at a depth of 24 inches. It has a high moisture-holding capacity and low organic-matter content.

Soil No. 56 is a clay from the Haiku district, Maui, Kaupakalua section of the Haiku Pineapple Co. The soil is typical of the pineapple soils of this district. It is a light-brown acid surface soil of good fertility notwithstanding the fact that the clay fraction is very high. It has a specific gravity of 3.24.

FIGURE 5.—Soil formation in situ. Large, exposed bowlder undergoing decomposition. Note stratification (soils Nos. 65 and 66) in central part of bowlder

Soil No. 57 is a clay and the subsoil of soil No. 56, taken at a depth of 20 inches. In all characteristics it is similar to soil No. 56.

Soil No. 65 is a clay from the side of an exposed bank at the end of Honokohau Gulch, Maui, near the sea, at an elevation of 100 feet. This is a yellow, inorganic, very colloidal subsoil of considerable depth resulting from the decomposition of the parent rock in situ. The soil appears as a clearly defined stratum and is conspicuously visible from a long distance. The width of the stratum is only about 2 feet. The soil is low in organic matter and is slightly alkaline in reaction, indicating an accumulation of basic elements. Weathering takes place under very hot and dry conditions. In moisture-holding capacity the soil is high.

Soil No. 66 is a clay from the same exposed bank at the end of Honokohau Gulch, Maui, from which soil No. 65 was taken. This subsoil, many feet deep and of red color, covers soil No. 65 as a separate and clearly defined layer. In physical characteristics, except color, it is similar to soil No. 65. Both soils are extremely colloidal in nature. (Fig. 5.)

Soil No. 69 is a clay from the Lahaina district, Maui, near Olowalu. This clay is apparently alluvial in origin and is very sticky and plastic, and of very low organic content. It was taken at sea level where there is underground seepage of sea water. The colloid complex is saturated with sodium. In addition, the soil contains a considerable amount of calcium, in the form of carbonate, from disintegrating coral beds underlying the clay. On this account the nature of the soil changes at about 12 inches in depth from clay to sandy clay. It is alkaline in reaction and is high in calcium.

Soil No. 76 is a clay from field 17, section 2, Makee Sugar Co., Kealia, Kauai. This highly calcareous clayey topsoil was taken at a depth of 4 inches at approximately sea level. Surrounded by fertile cane land giving good yields, this area presents an anomalous condition causing stunted vegetation. The soil is alkaline in reaction due to the calcium carbonate in the layer below.

Soil No. 77 is a clay and the subsoil of soil No. 76, taken at a depth of 24 inches. It is very much lower in organic matter than soil No. 76, and contains large amounts of calcium carbonate. In both soils Nos. 76 and 77 the percentages of colloids are rather low, showing that in all probability the anomalous condition is due to unfavorable soil reaction and excessive sodium and calcium content.

CERTAIN PHYSICAL PROPERTIES OF HAWAII SOILS

TEXTURE

The various weathering agencies which enter into soil formation in different combinations and to varying degrees affect the final decomposition product considerably. The texture of the product depends chiefly on the nature of the weathering agencies and the length of time they have been at work—that is, the age of the weathered product. When weathering is chiefly of a physical nature, the resulting soil is usually coarser in texture than when disintegration is caused by chemical changes, such as occur in humid climates. Moreover, the resulting soil is usually more evenly divided in the different fractions when weathering is chiefly physical. The difference in solubility is also a factor when textural differences are considered. Quartz, on account of its low solubility, persists longer in the coarser fractions, whereas minerals of a less resistant nature, such as feldspars, hornblende, and augite, concentrate gradually in the finer fractions. It is not surprising, therefore, to learn, in the case of Hawaii soils, the parent material of which consists largely of the last three minerals mentioned, that the finer separates, such as the fine silts and clay, are present in larger amounts than in most of the mainland soils.

The soils of Hawaii are on the whole heavier than those of the mainland of the United States, inasmuch as they contain larger percentages of the fine fractions, especially clay. Most soils belong to the clay and clay-loam types, these designations being in accordance with the United States Department of Agriculture Bureau of Chemistry and Soils classification on the basis of mechanical analysis. The Appendix gives the mechanical analyses of 78 Hawaii soils, as determined by means of the rapid hydrometer method of Bouyoucos (*5*, *6*).

The degree of agreement of this method of mechanical soil analysis with that of the pipette method is given elsewhere in this bulletin (p. 37). It may be stated here that the agreement has been fairly good, especially with heavy soils, and for this reason the rapid hydrometer method appears to be adapted to Hawaii soils, especially for routine determinations. Dennett (*16, p. 375*) and Steele (*34, p. 31*) found the same to be true with heavy soils of other countries.

Of the 78 soils examined for textural characteristics, 49 were found to be clay (2 sandy clay), 22 clay loam (15 sandy clay loam), 5 sandy loam, and 2 silt loam.

In the figures given in the Appendix, the limits in the diameter range for the different grades of particles do not correspond to

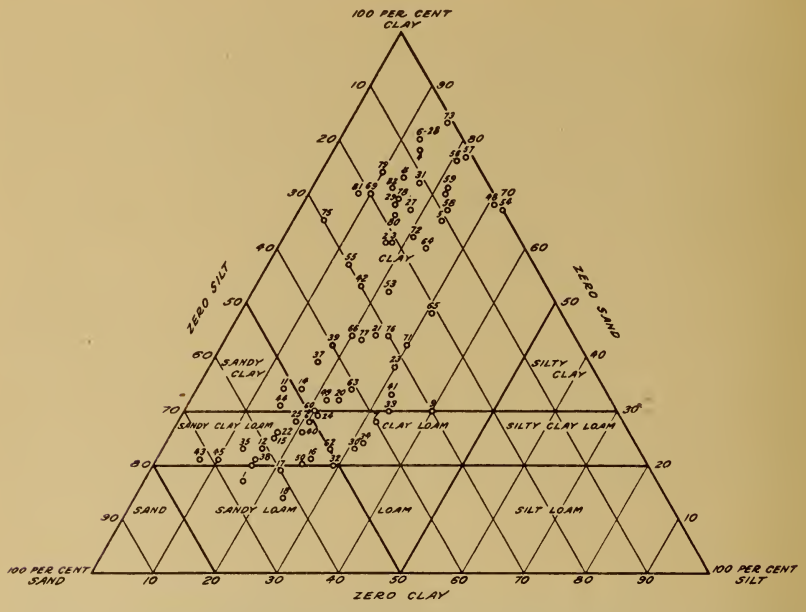

FIGURE 6.—Diagram showing the distribution of 71 Hawaii soils into the principal soil classes on the basis of mechanical analysis

those used in the United States Department of Agriculture Bureau of Chemistry and Soils (sand particles from 2 to 0.05 millimeters in diameter, the silt particles from 0.05 to 0.005 millimeters, and the clay particles less than 0.005 millimeter in diameter), but the different textural subdivisions are taken in the meaning of Bouyoucos (*5, p. 320; 6, p. 234; 7, p. 475*). He states that the rapid hydrometer method includes a part of the fine silt fractions in the clay or colloid fraction and that a part of the silt fraction is included in the fine sand.

The soil classes obtained by the rapid hydrometer method were checked in the case of 21 soils with the method of repeated sampling at a certain depth in order to obtain a comparison. The soil classification obtained was the same by both methods for 14 of the 21 soils. In the other 7 slightly different classification was obtained due to

the facts that they were lying near the border line of two or more classes and the experimental error involved or the inherent nature of the methods used caused these soils to be put in different classes. Furthermore, the rapid hydrometer method does not take into consideration the specific gravity of the soil. With soils like most of those of the United States this would introduce only small error, because the range there in the fluctuation of the specific gravity is small. However, in the case of Hawaii soils, where the specific gravity might vary between 2.2 and 3.4, this variation introduces considerable error. As will be shown later (p. 40), in the case of the detailed hydrometer method where the factors of temperature and specific gravity have been given due consideration, the agreement between the two methods is very good.

It is customary, especially with a large number of soil samples, to show diagrammatically the distribution of soils into the different soil classes on the basis of mechanical analysis, the equilateral triangle method being used for the purpose. Figure 6 shows graphically the distribution of 71 soils into the principal soil classes, and their percentage composition of sand, silt, and clay.

In order to obtain a better picture of the fine fraction of these soils, a mechanical analysis was made in which the silt fraction was divided into three groups. All particles below 0.002 millimeter equivalent diameter were considered as colloidal and were classed as such. This limit for colloids has been retained throughout the bulletin. Table 3 gives the detailed mechanical analysis, the classification obtained therefrom, the percentage of organic matter, and the soil reaction, expressed as pH values, of 21 Hawaii soils.

TABLE 3.—*Mechanical analysis,*[1] *percentage of organic matter, soil reaction expressed as pH, and classification of 21 Hawaii soils*

Soil No.	Mechanical subdivision					Organic matter	Reaction pH	Soil classes [2]
	Sand (0.02 millimeter)	Silt (0.01 to 0.02 millimeter)	Fine silt (0.005 to 0.01 millimeter)	Very fine silt (0.002 to 0.005 millimeter)	Colloids (0.002 millimeter)			
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
2	25.2	8.0	8.7	5.8	51.5	3.94	8.23	Clay.
6	15.7	3.9	6.4	7.4	66.6	3.89	8.73	Do.
9	34.0	12.5	10.5	16.0	27.0	18.52	4.80	Clay loam.
12	55.0	12.0	7.0	11.0	15.0	15.75	5.87	Sandy clay loam.
15	68.5	8.0	5.4	8.6	9.5	25.52	5.77	Do.
17	69.5	7.2	2.5	9.0	11.8	8.49	6.50	Sandy loam.
21	38.5	10.1	12.1	15.4	23.9	13.36	6.55	Clay.
23	45.5	15.0	12.0	12.0	15.5	12.45	7.17	Do.
31	16.5	6.9	11.6	15.6	49.4	8.15	7.40	Do.
33	54.0	15.0	9.0	5.0	17.0	10.95	6.70	Do.
37	40.9	9.1	10.7	16.2	23.1	11.56	6.36	Do.
42	34.0	8.0	8.7	16.8	32.5	9.07	6.50	Do.
48	11.2	14.7	20.6	23.4	30.1	6.67	5.97	Do.
49	55.7	9.8	6.0	7.2	21.3	2.34	5.77	Do.
56	12.8	9.2	11.8	18.2	48.0	7.10	4.75	Do.
57	16.2	9.4	10.9	14.4	49.1	6.27	5.03	Do.
65	26.7	18.9	11.6	7.7	35.1	5.09	7.42	Do.
66	42.2	10.9	7.6	8.7	30.6	2.32	7.25	Do.
69	14.2	8.4	13.6	14.9	48.9	1.22	7.77	Do.
76	28.2	21.6	8.6	15.8	25.8	7.70	7.72	Do.
77	53.0	6.9	6.8	5.2	28.1	1.91	7.74	Sandy clay loam.

[1] Mechanical analysis by a modified pipette method.
[2] Soil classes according to specifications given by R. O. Davis and H. H. Bennett (*15*).

Since there is no agreement on the part of various investigators as to the limit in size of the various separates, it is thought best to express the figures obtained in a mechanical analysis as summation percentages as Robinson (*30, p. 307*) suggests, and to plot the different points obtained, connecting them by a curve. In this manner

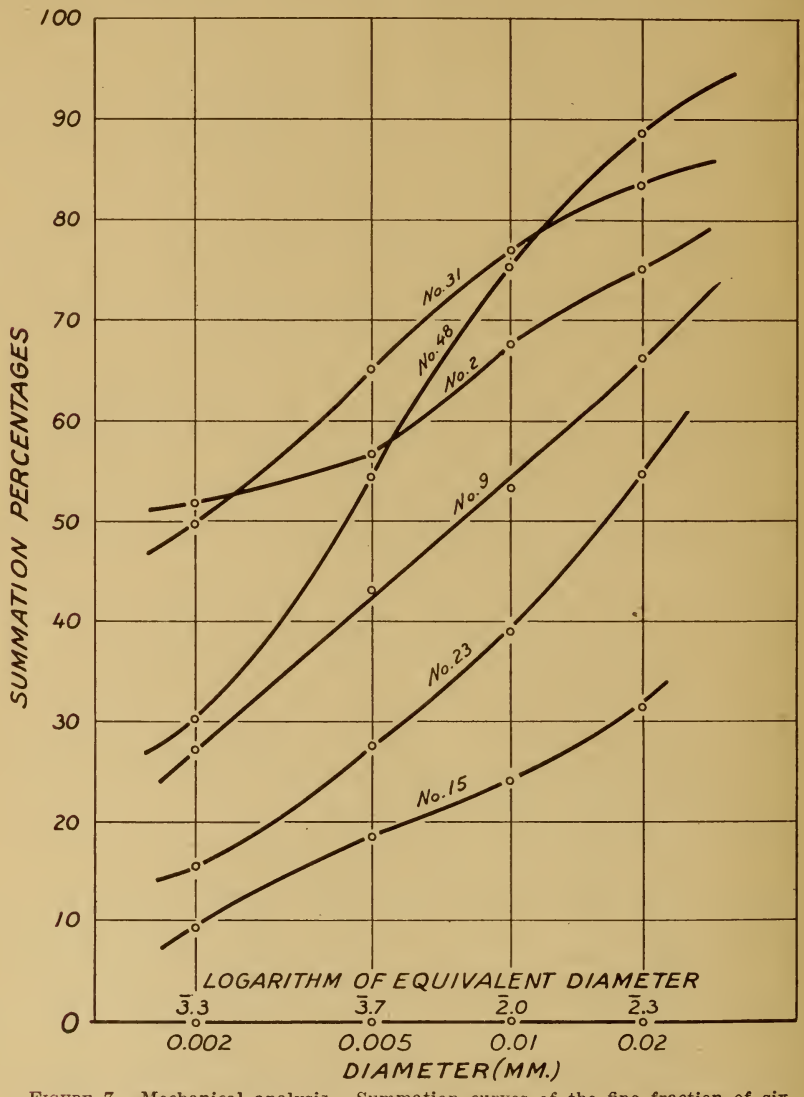

FIGURE 7.—Mechanical analysis. Summation curves of the fine fraction of six Hawaii soils

any intermediate point may be obtained by interpolation. The term "equivalent diameter" is used instead of "diameter" for obvious reasons, and the logarithm of the equivalent diameter is plotted instead of the equivalent diameter itself to avoid crowding the points. Figure 7 shows graphically these summation curves for six soils. In this manner smooth curves are obtained, making interpolation easy,

and enabling the reader to interpret one method of analysis in terms of another. These curves represent six typical Hawaii soil types. Curves Nos. 2 and 31 represent certain heavy types, and curve No. 15 represents certain light types of soil.

SPECIFIC GRAVITY

In view of the fact that the true specific gravity of soils had to be used in several phases of the investigation, especially those involving the use of Stokes' formula of settling particles, it became desirable to determine the magnitude of variations in the specific gravity of Hawaii soils.

In soils formed from siliceous rocks under arid or semiarid conditions, such as are most of the mainland soils, containing large amounts of quartz and feldspar and only a small amount of iron-bearing minerals and a small percentage of organic matter, the specific gravity varies between the narrow range of 2.6 and 2.7. This is due to the fact that the quartz and the feldspar making up the larger part of the mineral portion have a specific gravity of 2.65 and 2.57, respectively. Compounds causing a deviation in specific gravity from these figures are manganese, iron, and aluminum compounds, and organic matter. Table 1 shows the modifying effect upon the specific gravity of soils of these compounds when they are present in larger amounts.

In view of the above-mentioned facts, it is natural to expect mainland soils and tropical volcanic soils to exhibit considerable difference in specific gravity. It has been shown that with submicroscopically porous materials varying results are obtained when different liquids are used in the determinations of true specific gravity. In these determinations water and toluol were used, but in applying the figures to Stokes' law the specific gravity as determined in water was used. The determinations were made as follows:

The soil material was ground to pass a 60-mesh sieve and was dried in an electric oven at 110° C. for at least 18 hours. A 50 cubic centimeter soil pycnometer was half filled with recently boiled distilled water and weighed. From 6 to 8 grams of the oven-dried soil was added, the whole weighed and then boiled for five minutes to expel any air occluded in the interstices of the soil particles. When the pycnometer had cooled and the soil particles had settled, leaving the supernatant liquid clear, it was filled with water to the point of overflow. The pycnometer and contents were brought to the temperature at which the determinations were made (30°), the ground-glass stopper was inserted, the liquid which had overflowed was removed, and weighing was quickly done. Duplicate determinations made in this manner usually checked within 0.05.

In several instances the true specific gravity was determined, toluol being used. In most cases the agreement was good, the average being 2.88 in toluol as compared with 2.8 in water, where both determinations were made. In determining the apparent specific gravity or volume weight, the same soil material was used as in the true specific gravity determinations. A tared glass cylinder graduated to 50 cubic centimeters was filled with the soil to the upper mark, dropped 4 to 6 inches a number of times until compacting was no longer noticeable, when the volume was noted and the soil with the cylinder weighed to 0.1 gram.

Table 4 shows the true and apparent specific gravities of 21 Hawaii soils as determined by the procedure described above, and the porosity of these soils as calculated from the two specific gravities.

TABLE 4.—*Specific gravity and porosity of Hawaii soils*

Soil No.	True specific gravity	Apparent specific gravity	Porosity	Soil No.	True specific gravity	Apparent specific gravity	Porosity
			Per cent				*Per cent*
2	2.83	1.25	55.8	48	3.36	1.32	60.7
6	2.98	1.32	55.7	49	2.70	1.06	60.7
9	2.19	.66	69.9	56	3.24	1.32	59.3
12	2.53	.93	63.2	57	3.31	1.25	68.3
15	2.31	.98	57.6	65	2.86	1.04	63.6
17	2.79	1.19	57.3	66	2.98	.94	68.5
21	2.57	1.04	59.5	69	2.90	1.17	59.7
23	2.52	1.04	58.7	76	2.92	1.09	62.7
31	2.79	1.16	58.4	77	2.96	1.14	61.5
33	2.68	.93	65.3				
37	2.52	.96	61.9	Average	2.80	1.09	61.5
42	2.84	1.04	63.4				

As was anticipated, large variations were obtained. Soils with larger percentages of organic matter gave on the whole much lower figures than soils of low organic content. The lowest figure recorded was 2.19 for soil No. 9—a highly organic, light-gray soil containing 18.5 per cent organic matter; whereas the highest figure recorded was 3.36 for soil No. 48—a brownish-red, ferruginous clay of 6.67 per cent organic content. The average for all the soils was 2.8 despite the fact that the series contained several abnormally organic soils which lowered the average. In the case of soils the organic content of which was below 10 per cent, the specific gravity averaged 2.96, whereas for soils the organic content of which was over 10 per cent the specific gravity averaged 2.47.

In determining the volume weight or apparent specific gravity, it is realized that the figures are only approximate and that they do not represent actual field conditions in so far as structural relationships are concerned. The high percentage of organic matter in Hawaii soils is one of the main determining factors and is often the cause of considerable variation. On the whole, the apparent specific gravity of Hawaii soils is much lower than that of the mainland soils partly for the above-mentioned reason and partly on account of the finer texture. For the whole series it averaged 1.1, the values fluctuating between 0.66 in soil No. 9, a highly organic kind, to 1.32 in soil No. 6, an inorganic clay resembling adobe.

The percentage of pore space calculated from the specific gravities indicates the fine texture of the Hawaii soils. As is known, coarse soils are much heavier than fine soils, because of the nature of the contact of the particles and their disparity in resisting compaction. The method employed in determining the apparent specific gravity, when disturbed soil is used, gives lower results for that constant than does either the iron-cylinder or the paraffin-immersion method. On mainland soils the apparent specific gravity determined by the iron-cylinder and the paraffin-immersion methods gave results 0.4 higher

than the laboratory method on disturbed soil. For this reason the pore space calculated in Table 4 is somewhat too high, even though the figures are comparative. The average porosity for the soil series was 61.5. This figure agrees well with the average of the moisture-holding capacity of the series, which was 64.7, in view of the fact that when the soil is completely saturated with water all the pore space is occupied by water.

MOISTURE RELATIONSHIPS

Of all physical constants which are determined on soils, those involving moisture relationships are the most important and the most indicative of the true nature of soil. As a matter of fact, the moisture coefficient may be said to be regarded as a kind of summation index of several physical and chemical characteristics, such as texture, apparent specific gravity, chemical composition, humus content, and colloidal content. Both from a theoretical and a practical standpoint it is important to know the nature and amount of the various soil moistures and their relationships to plant nutrition. It is well known that the different moisture constants vary between very wide limits for different soil types and sometimes vary considerably even with soils belonging to the same type. This is true especially of Hawaii soils which, by virtue of their peculiar chemical composition and physical characteristics, show great variation in their moisture relationships.

To obtain a more or less true picture of the moisture relationship existing in Hawaii soils of different types, a number of soils were examined for their moisture-holding and moisture-adsorbing properties. The various physical and chemical properties of these soils which affect their moisture relations varied between wide limits. These data are given in Tables 1, 2, 3, 4, and 5, and in the Appendix.

The moisture constants determined for these soils were the hygroscopic and capillary moistures, the moisture-holding capacity, and the moisture equivalent. It should be stated that notwithstanding the use of standard methods and of precautions to secure uniformity in conditions surrounding the determinations, the results do not represent actual field conditions for obvious reasons. In the first place the textural and structural conditions of the soil as they exist in the field have been disturbed, and their moisture characteristics have thus been altered. This is an unavoidable source of error in most determinations, and in order to obviate it attempts are made to subject all soils approximately to the same degree of alteration by applying uniform preliminary treatment in the laboratory. In the second place, in most colloidal soils upon air drying a change seems to take place in the colloidal complex which alters the moisture-adsorbing power to a considerable degree. This alteration may take place to different degrees depending on the nature of the colloidal phase and to the extent the soil has been subjected to drying.

Some soil investigators believe that the moisture properties are altered to a certain extent immediately upon the removal of the soil from the ground to a container. As an extreme example to illustrate this point: Certain soils from the Olaa district, Hawaii, having been formed under extreme rainfall and poor drainage conditions are almost constantly in a water-saturated condition. As a result,

they have developed high moisture-holding power no doubt due to excessive hydration and probably to the structure of the colloidal complexes in which their high organic matter plays no small rôle. Some of these soils hold as much as 500 per cent of water figured on the dry basis (*33, p. 423*). Upon being air dried, however, they do not return to their former physical condition when moistened with water—a fact indicating the irreversible nature of the reactions taking place in the colloidal phase. This fact also indicates that these soils in situ have never been deprived of their moisture to any appreciable degree.

The hygroscopic-moisture content was determined by exposing the powdered soil to an atmosphere saturated with water vapor over 3.3 per cent sulphuric acid at 30° C. for six days, when the gain in weight was determined by drying to constant weight. The various factors entering into this determination, such as effect of time, vapor pressure, temperature, degree of vacuum, and size of particles, have been thoroughly investigated by Middleton (*26, p. 455*), whose findings were observed in these determinations. The amount of hygroscopic water which the soil holds under ordinary air-dry conditions was also determined. The soil was brought to a constant weight by drying it at room temperature, 28° to 32° C., at a relative humidity of approximately 50 per cent, and the moisture content was determined by drying in the oven at 110° for 18 hours or longer. The percentage of moisture was calculated on an oven-dry basis, both in this and in the other moisture-constant determinations.

The capillary moisture was determined by filling a tared glass tube, 1 inch in diameter by 15 inches in length and fitted with a copper-gauze bottom, with air-dried soil to the 12-inch mark, and dropping the tube repeatedly 4 to 6 inches until compacting was no longer noticeable, when the weight was recorded. The base of the tube was then placed in a pan of water, until the water rose to the surface of the soil. Then the tube was removed from the water, placed on a blotting pad to remove excess moisture, and weighed. The time required for the surface to become moist was also recorded.

The moisture-holding capacity was determined on the same sample on which capillary moisture was determined. The tube holding the soil plus capillary moisture was placed in a cylinder of water the level of which was the same as that of the soil, and was allowed to remain until the soil had become thoroughly saturated. At this point the tube was removed, drained of excess water, and weighed.

The moisture equivalent was determined according to the specifications of Briggs and McLane (*8, p. 140*). Approximately 30 grams of soil on an oven-dried basis was placed in the centrifuge cups the wire-gauze bottom of which was first covered with a sheet of filter paper. The cups of soil were then thoroughly moistened by placing them in a shallow pan containing water to a depth of one-fourth to one-half of an inch. The cups were allowed to stand overnight in the pan during which time they were suitably covered to protect against evaporation.

The time of centrifuging was 30 minutes at a rate of 2,440 revolutions per minute at the end of which the moisture retained was determined by drying to constant weight at 110° C.

The various moisture constants obtained are given in Table 5 and are shown graphically in Figure 8.

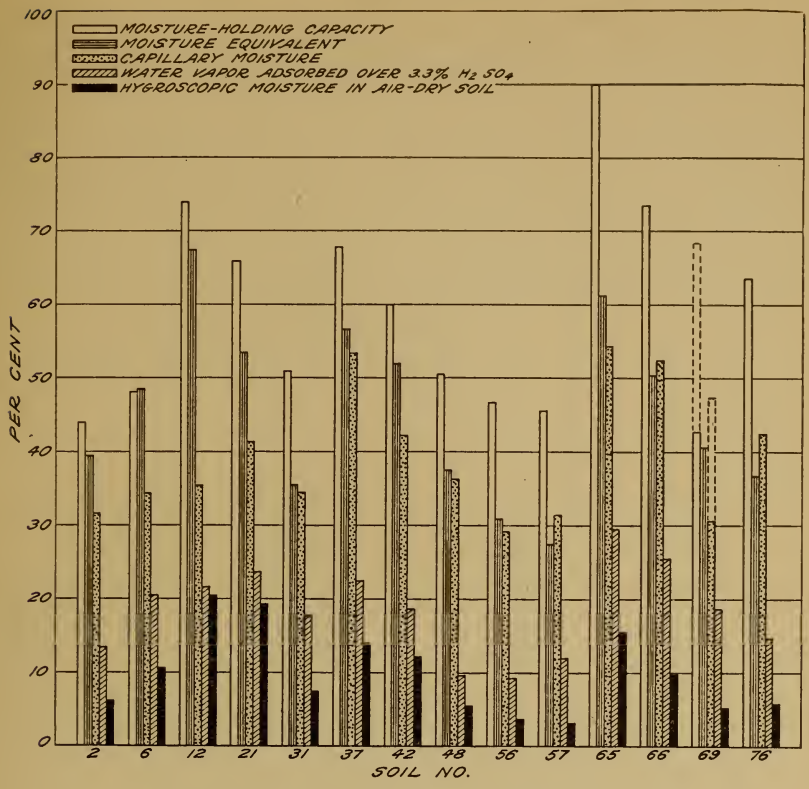

FIGURE 8.—Relation between various moisture constants

TABLE 5.—*Moisture relationship in Hawaii soils*

Soil No.	Hygroscopic moisture	Water vapor adsorbed over 3.3 per cent H_2SO_4	Capillary moisture	Rate of capillary rise	Moisture-holding capacity	Moisture equivalent
	Per cent	*Per cent*	*Per cent*	*Days*	*Per cent*	*Per cent*
2	6.1	13.3	31.8	16	43.9	39.6
6	10.8	20.8	34.3	14	48.1	48.5
9	10.0	----------	77.7	8	119.6	67.2
12	20.5	21.6	35.4	5	74.1	67.5
15	14.0	----------	----------	----------	----------	42.7
17	3.1	----------	----------	----------	----------	21.9
21	19.3	23.7	41.6	4	66.0	53.4
23	15.8	----------	45.1	4	63.5	46.1
31	7.4	17.8	34.5	4.7	51.0	35.4
33	15.7	----------	49.4	1	79.8	61.8
37	13.9	22.6	53.5	.9	67.9	56.7
42	12.2	18.6	42.3	1	60.0	52.0
48	5.5	9.7	36.1	1.8	50.6	37.7
49	21.1	----------	53.2	1.8	89.6	71.3
56	3.8	9.3	29.1	4.8	46.9	30.9
57	3.1	12.0	31.4	2.9	45.5	27.4
65	15.5	29.6	54.2	27	90.0	61.2
66	9.9	25.6	52.5	3	73.5	50.4
69	5.2	18.8	30.6	35	42.9	40.7
76	5.8	14.8	42.5	2	63.6	36.9
77	5.3	----------	41.9	.8	53.7	31.1
Average	10.7	18.4	43.0	----------	64.7	46.7

In a discussion of these results, the very good parallelism between the various moisture coefficients is probably the most striking fact. This is not at all surprising when one considers that while the different forms of water in the soil are held by different physical forces or different combinations of such forces, the factors determining the magnitude of these forces are the same in every instance, namely, texture and organic matter. These two factors exert their influence in varying degrees and proportions. From a textural point of view the amount of moisture adsorbed or held depends on the surface exposed, and for this reason soils containing large amounts of fine

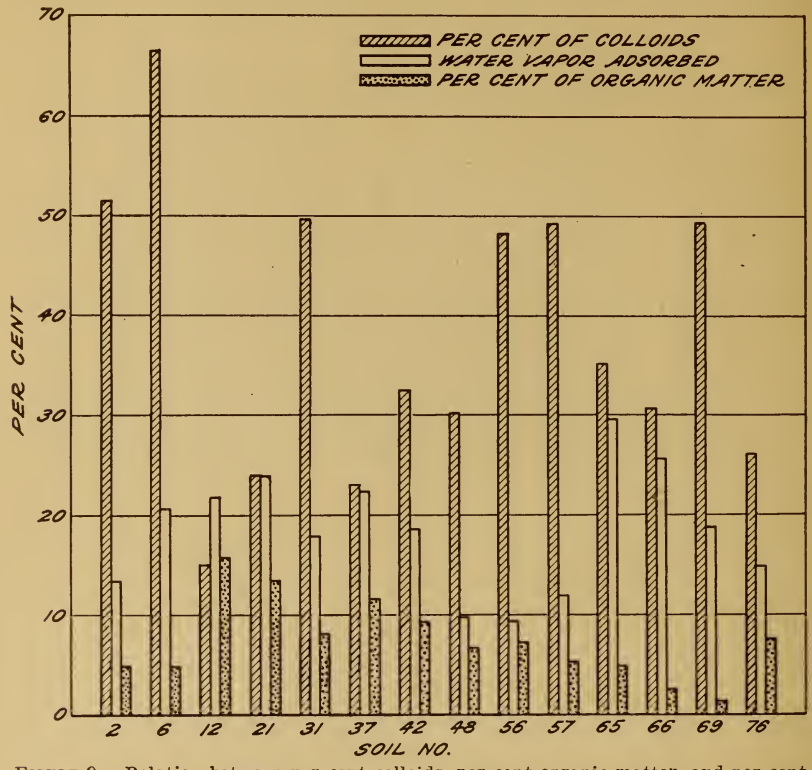

FIGURE 9.—Relation between per cent colloids, per cent organic matter, and per cent water vapor adsorbed

matter or colloids adsorb or hold much more moisture than soils containing small amounts of such matter. The same relationship exists between organic matter and moisture held or adsorbed. Furthermore, since usually all the organic matter is a part of the colloidal fraction on the basis of particle size, it may be said with a good degree of accuracy that the moisture properties of soils depend on the colloidal fraction—organic and inorganic.

To permit study of the relationship between organic-matter content, colloidal content as determined by mechanical analysis, and moisture properties of soils, these three factors were plotted in Figure 9. The surprising feature of this diagram is that the hygroscopic moisture not only does not follow the colloid content but in the larger number of cases there is an inverse relationship. However, the hygroscopic moisture conforms more or less to the per cent organic matter.

This fact suggests the existence of large disparity between the adsorptivity of organic colloids and inorganic colloids. It further suggests the possibility that organic matter, or at least a part of it, may exist in the coarser-than-colloid fractions, such as silt, fine silt, and very fine silt fractions, and that the organic matter in these fractions shows power of adsorptivity. It matters little whether or not the organic matter in these coarser-than-colloid fractions is in ultimate particles or exists simply as colloidal aggregates or as coating around inorganic particles which resist successfully all efforts of dispersion, so long as they show power of adsorptivity. That large disparity exists between the hygroscopicity and water-holding capacity of the inorganic and organic soil constituents can be seen from Table 6.

TABLE 6.—*Water-holding capacity and hygroscopicity of certain soil constituents* [1]

Soil constituent	Water-holding capacity according to—			Hygroscopicity
	Schubler	Trommer	Wollny	
	Per cent	*Per cent*	*Per cent*	*Per cent*
Quartz sand	25	26–32	19.4–29.1	0
Limestone	85	80		1
Clay (kaolin)	87	70	45.9–55.9	5–25
Humus	181	180	106.5–253.6	25–50

[1] Mitscherlich (*27, p. 138*).

Table 6 indicates that the moisture-adsorbing power of humus is on the average about two and one-half times as great as that of pure clay; the average water-holding capacity of humus about three and one-third times that of clay. This explains the fact that certain soils high in organic matter, such as many of the Hawaii soils, show high adsorptivity despite the fact that their clay or colloidal fraction is relatively low. On the other hand, it is easily possible for a soil with a high colloidal fraction to show a relatively low adsorptivity. As the organic-matter content of the soil increases the hygroscopicity rises rapidly.

That this disparity in hygroscopicity between the various soil constituents may easily obscure the parallelism between amount of clay or colloids as determined in a mechanical analysis and the hygroscopicity of the soil is illustrated by Lyon and Buckman (*23*) in the case of mainland soils. Table 7 shows the hygroscopic coefficient compared with other soil factors.

TABLE 7.—*The hygroscopic coefficient compared with certain other soil factors* [1]

Soil	Hygroscopic coefficient	Clay	Loss on ignition	Humus
	Per cent	*Per cent*	*Per cent*	*Per cent*
Dunkirk silty clay loam (surface)	3.80	12.9	5.08	1.26
Dunkirk silty clay loam (subsoil)	5.77	20.0	3.05	.20
Clyde clay loam (surface)	18.90	20.1	14.54	4.34
Vergennes clay (subsoil)	17.40	74.5	5.79	.49

[1] Lyon and Buckman (*23*).

In the case of the first two soils mentioned, the determining factor for the hygroscopic coefficient is the percentage of clay, the humus content being small. However, in the case of the last two soils mentioned, the amount of organic matter is the dominant factor. The Clyde clay loam, although possessing only 20.1 per cent clay, shows a higher hygroscopic coefficient than the Vergennes clay, the clay fraction of which is 74.5 per cent. A comparison of the Dunkirk subsoil with the Clyde clay shows that they both possess the same amount of clay, yet the Clyde soil has a hygroscopic coefficient over three times as large as that of the Dunkirk soil, due to the disparity in humus.

In the above-cited example the magnitude of the humus content ranged from 0.2 per cent to 4.34 per cent, small figures, relatively speaking, as compared with the percentage of organic matter in Hawaii soils. If such disparity is possible with soils containing from 0.2 to 4.34 per cent of organic matter, it is logical to assume that much larger differences are possible with soils containing from two to three times that amount of organic matter. This actually is the case with Hawaii soils. The wide limits between which the organic-matter content of Hawaii soils varies explains the wide limits obtained for the moisture constants themselves.

The moisture-equivalent figures vary between 21.9 and 71.3 per cent, the average of the whole series being 46.7 per cent. Considerable variations were obtained for this moisture constant even within the same soil type. For instance, soils Nos. 57 and 9, which are classified as clay and clay loam, on the basis of mechanical analysis, had moisture equivalents of 27.4 and 67.2 per cent, respectively. In this case the large difference in the respective organic-matter content (6.27 and 18.52 per cent) may explain the disparity in the moisture equivalent. However, in the case of soils Nos. 2 and 49, the moisture equivalents of which were 39.6 and 71.3 per cent, respectively, the difference in organic-matter content does not explain this disparity (organic matter 3.94 and 2.34 per cent). This case is all the more remarkable because soil No. 2, with the lower moisture equivalent, is a clay with 51.5 per cent colloids, whereas soil No. 49, with a moisture equivalent almost twice as great as that of soil No. 2, is a clay with only 21.3 per cent colloids.

These discrepancies may be explained by the considerable differences that may exist in the chemical composition of the inorganic colloids, and by the amount and nature of the coarser-than-clay fractions, such as silts and fine silts. As will be pointed out later (p. 25), the chemical composition, especially the silica-sesquioxide ratio, may vary very considerably in the different fractions of the same soil.

Similar discrepancies in moisture equivalents are noted in the figures published by Bennett and Allison (*4*, *pp. 21*, *22*, *308*) in the case of Cuba soils. For instance, Alto Cedro clay No. 32828, with a clay content of 52.1 per cent, gave a moisture equivalent of 75.2 per cent, whereas Nipe clay No. 32830, with a clay content of 44.5 per cent, gave a moisture equivalent of 23.7 per cent. Both soils are very low in organic matter. In this instance the low moisture-retaining capacity of the Nipe clay is attributed by the authors to certain physical peculiarities, notably to large pore space.

If the wilting coefficient is calculated by dividing the moisture equivalent by the Briggs and Shantz factor 1.84 (*9, p. 58*), the figure 25.3 will be obtained for the whole series. This average figure agrees well with experimentally obtained data. Hartung (*19, p. 15*), working with pineapples, noted that no root growth took place when the moisture content fell below 22.5 per cent. Feeble efforts at root development took place between 22.5 and 27.0 per cent moisture content.

Farden (*17, p. 157*) determined experimentally the wilting coefficient for three different soils on which pineapple plants were growing, and obtained 23.6, 25.7, and 27.8; correlating these figures with the moisture equivalent, which was also determined, he calculated the factor, which he found to be 1.45, 1.4, and 1.46—figures much lower than the Briggs and Shantz factor. Although the factor 1.84 is approximately applicable for an over-all average, the factor apparently varies considerably and must be determined experimentally for different soil types. However, the critical moisture point of Hawaii soils may safely be said to be about 25 per cent. This figure agrees well with results obtained in tests with Porto Rico and Cuba sugarcane soils. These soils, as is known, are somewhat similar to Hawaii soils, being red, laterites, and lateritic. Crawley, as quoted by Bennett and Allison (*4, p. 307*) observed that certain Porto Rico clay-land cane suffered where the soil contained 23.5 per cent, and the subsoil 24.3 per cent of moisture. He was also of the opinion that "where the moisture in Cuban 'red soil' is reduced below 25 per cent, cane will suffer."

RELATION OF ORGANIC AND INORGANIC PROPERTIES TO ADSORPTION

ORGANIC PHASE

It has already been stated that in most cases the amount of organic matter present is the determining factor in the moisture relationships in Hawaii soils. It has been suggested as a possibility that all the organic matter does not exist in the clay or colloidal fraction of a mechanical analysis, and that a part of the organic matter, on account of the size of the particles, is present in the subdivisions of silt. Logically, it may be supposed that the soil organic matter undergoing decomposition passes through different gradations in particle size before assuming colloidal dimensions. In these investigations all particles smaller than 0.002 millimeter in equivalent diameter are considered as colloidal. With the realization that this limit is an arbitrary one, it is reasonable to suppose that the organic matter shows adsorptive power before reaching this arbitrary limit. It may be argued that organic material existing in this coarser state is simply colloidal aggregates resisting dispersion, but for practical considerations they are particles of silt dimensions exerting their power of adsorption in that subdivision. Further, the organic matter is often stated to exist chiefly as coating around particles of colloidal dimensions, but it is reasonable to suppose that it also exists as coating around the fine silt particles. Moreover, coarser particles of decomposing organic material may have a highly adsorptive coating

around them, since humification is taking place outwardly and is working inwardly, gradually diminishing the size of the particles.

That the foregoing considerations apply in considerable degree to organic Hawaii soils is indicated by the phenomenon that the adsorptivity of soils often approximates the adsorptivity of the colloids extracted therefrom and in some instances exceeds it. This will be shown later (p. 34), when the determination of the colloidal fraction by the water-vapor adsorption method is considered.

To obtain an idea of the extent to which organic matter was present in the combined silt and sand fractions, the loss on ignition of this fraction was calculated for several soils from the loss on ignition of the whole soil, that of the extracted colloid, and from the mechanical analysis. Table 8 shows the comparison of loss on ignition of the colloidal and noncolloidal fractions in these soils.

TABLE 8.—*Comparison of loss on ignition of colloidal and noncolloidal fractions in Hawaii soils*

Soil No.	Soil	Colloids		Noncolloids (sand and silt)	
	Loss on ignition	Amount	Loss on ignition	Amount	Loss on ignition
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
6	10.0	66.6	10.6	33.4	8.80
9	30.0	27.0	19.7	73.0	33.81
12	32.8	15.0	43.9	85.0	30.84
31	16.3	49.3	17.5	50.7	14.71
42	25.0	32.5	24.6	67.5	25.19
48	13.0	30.1	15.3	69.9	12.01
65	9.4	35.1	9.0	64.9	9.62
66	9.6	30.6	8.6	69.4	10.04
76	14.3	25.8	19.0	74.2	12.67
77	18.9	28.1	18.8	71.9	18.94

Table 8 shows that a considerable portion of the organic material is often obtained in the noncolloidal fraction. In most instances the loss on ignition of the noncolloidal fraction is close to that of the colloidal fraction and in some instances exceeds it. In the case of soil No. 9, a highly organic type, a much higher percentage of organic material is indicated in the noncolloidal fraction than in the colloidal.

INORGANIC PHASE

When the percentage of the organic matter is not the determining factor in soil-moisture properties, such as water-vapor adsorption, the texture of the soil partly determines that property. Structural character plays a rôle also, but under laboratory conditions this factor is eliminated. That the chemical composition of the inorganic phase plays a significant rôle has been indicated already where it was shown that two soils equally low in organic-matter content may have nearly the same percentage of clay fraction, and yet one soil may have more than three times as great a moisture equivalent as the other (see p. 22). Of course, this phenomenon may be noted not only in the case of moisture equivalents, but also with other moisture constants, such as hygroscopic moisture, or for that matter with other physical properties, such as heat of wetting and adsorption of ions. That one may expect such behavior may be seen from the work of other investigators.

Anderson and Mattson (*3, p. 36*) show that a fairly constant relationship exists between the chemical composition and the properties of colloids. These investigators plotted the silica-sesquioxide ratio against the heat of wetting of eight different inorganic soil colloids and obtained a fairly straight line relationship, proving that chemical composition affects physical properties. The water-vapor adsorption, which was also determined on these colloids, showed the existence of a rather strict parallelism between heat of wetting and water-vapor adsorption. The percentage of water vapor adsorbed by these colloids was very nearly the same numerically as the calories evolved per gram of colloid on wetting, indicating that heat-of-wetting data may be used in lieu of water-vapor adsorption. In magnitude they ranged from 17.5 to 5.3.

Parks and Linebarger, as quoted by Alexander (*1, p. 451*), show that appreciable heat of wetting is given by substances which are larger than colloidal dimensions. Silica, when wetted, gave the following heat of wetting at different dimensions: Particles of 0.1, 0.02, 0.01, and 0.005 millimeter diameter gave 0.24, 0.89, 6.9, and 13.8 calories, respectively, per gram of substance. This indicates that in the case of silica at least particles much larger than clay or colloidal dimensions give considerable water-vapor adsorption. It may be logically assumed that other substances behave similarly.

Gore, as quoted by Alexander (*1, p. 451*), showed that aluminum oxide, manganese oxide, and ferric oxide gave widely differing figures for heat evolved when wetted with water. The heat evolved by aluminum oxide was about ten times that of ferric oxide (1.16° and 0.12° C. rise, respectively). According to Wollny, as quoted by Warington (*35, p. 62*), the rise in temperature when quartz sand, aluminum silicate, and hydrated ferric oxide were moistened with water was 0.1°, 0.83°, and 6.6°, respectively.

In view of these facts, it is easy to see that difference in chemical composition of the various fine fractions of any one soil considerably affects their moisture-adsorption properties, especially where large differences are involved.

To show that such large differences may exist, the silica-sesquioxide ratio was calculated for the different fractions of nine typical Hawaii soils. These figures are given in Table 9.

TABLE 9.—*The $SiO_2/Fe_2O_3+Al_2O_3$ (mol) ratio in the different fractions of some important Hawaii soil types*[1]

Soil No.	Soil fractions				
	Clay	Fine silt	Silt	Fine sand	Coarse sand
161	1.25	1.32	0.07	0.07	----------
291	2.17	1.88	1.47	1.28	1.04
292	1.97	2.00	1.68	2.54	2.31
339	1.28	1.34	1.23	1.18	1.12
392	1.03	.96	.66	.85	.64
428	.62	1.41	1.67	2.01	1.78
448	.33	.63	.51	.57	1.13
474	1.59	2.02	1.58	1.67	1.55
547	1.17	.84	.24	.22	.30

[1] These figures were calculated from the data published by McGeorge (*24, p. 8*).

Table 9 shows very large disparity in chemical composition of the various fractions in soil No. 547, and especially in soil No. 164. In these two soils the ratio of adsorptivity of the whole soil to that of the colloid extracted therefrom would not be expected to represent accurately the amounts of colloids present in the soil.

DISPERSION OF HAWAII SOILS

In connection with the mechanical analysis of soils, probably the greatest difficulty is had in obtaining a perfect dispersion. This difficulty is especially noticeable with certain highly organic soils and with soils the colloidal complex of which contains in the adsorbed state certain bases, such as calcium, which have a flocculating effect upon the soil suspension. Several suggestions have been made in the past few years by various workers both as to the mechanical means to be employed and as to the chemical treatment the soil should receive to insure as nearly perfect dispersion as possible. In the light of recent studies on the exchangeable bases, much valuable information has been obtained regarding the rôle of various bases in the dispersion and flocculation of clays. For instance, it is known that sodium clay is much more readily dispersed than ammonium or potassium clays. It would appear logical, therefore, to employ an alkaline solution of a sodium salt to obtain maximum dispersion.

Hawaii soils contain a larger amount of organic matter than do most soils of the mainland of the United States, and in certain areas, especially in the lowlands, highly calcareous soils exist. In addition, the soils are on the average heavier, containing upward of 50 per cent clay and fine silt. In view of these facts, an investigation was made to learn what manner of mechanical dispersion gives the most efficient results and what chemicals, if any are used, bring about complete deflocculation.

In the studies undertaken in the station laboratory, the work on dispersion was therefore divided into two parts, one comparing different mechanical means and their relative efficiency when the chemical treatment is constant, and the other comparing the efficiency of various chemical treatments when the mechanical method is constant.

In measuring the degree of dispersion, Bouyoucos' hydrometer was used: (1) Because under the same conditions (concentration and temperature) it gives comparable figures; (2) because mechanical analysis performed with the aid of it compared favorably with other standard methods; (3) because duplications carried out under identical conditions gave good agreements; and (4) because of its rapidity.

The five soils, varying widely in nature, selected for the work represented certain Hawaii soil types and were in most part typical of the larger soil areas. A description of these soils is given (p. 5).

MECHANICAL ASPECT

Three methods widely used in mechanical soil analysis were tried: (1) Rubbing in a mortar with a rubber pestle under water containing alkali (KOH) for varying lengths of time; (2) shaking in an end-over-end shaker in a machine revolving at the rate of about one revolution per second; and (3) using an electrical stirrer. The first method has been used by certain investigators, notably Engle and

Yoder, and has given good dispersion with some soils. The second method is being used rather extensively, especially by English workers, and is a part of the official pipette method. The third method has been suggested by Bouyoucos (*5*, *p. 321*), and consists of dispersing the soil in a specially constructed cup having baffles in the form of copper wires on its wall to act as obstructions. The machine used in connection with this method was a drink mixer with a rate of 10,000 revolutions per minute.

In every case 50 grams of soil oven dried at 110° C. for 18 hours or longer was used. The chemical treatment in each case was the same—that is, 5 cubic centimeters of normal potassium hydroxide in about 400 cubic centimeters of distilled water.

After dispersing for the required length of time the soil suspension was poured into graduated cylinders 45 centimeters high by 6 centimeters in diameter, and the volume was made up to 1,130 cubic centimeters with distilled water. At this concentration the hydrometer was graduated to read grams of solid matter in suspension. The suspension was then vigorously shaken for half a minute or so, the palm of the hand being used as a stopper. The cylinder was then immediately placed on the table, and the time was noted with a stop watch. The settling period was always 15 minutes, when the hydrometer reading was taken and the temperature correction made. Results are expressed as grams solid matter remaining in suspension per unit volume (1 liter) at the end of the settling period. Table 10 gives the results of these determinations. The first column represents the reading obtained when no mechanical means were used, the soil being simply shaken in the cylinder with the required amount of water (plus potassium hydroxide) for about half a minute and allowed to settle for the time prescribed.

TABLE 10.—*Degree of dispersion*

[Results expressed in grams per liter of solid matter in suspension]

RUBBING IN MORTAR WITH RUBBER PESTLE

Soil No.	Solid matter dispersed in—				
	0 minutes	15 minutes	30 minutes	45 minutes	60 minutes
	Grams	*Grams*	*Grams*	*Grams*	*Grams*
2	7.4	20.2	21.3	24.9	27.3
6	8.5	21.7	21.6	25.3	27.3
37	5.7	11.5	13.2	14.4	15.0
42	5.4	14.2	17.3	19.4	20.5
48	6.2	23.7	28.1	30.9	31.9

USING END-OVER-END SHAKER

Soil No.	Solid matter dispersed in—				
	0 hours	6 hours	12 hours	18 hours	24 hours
2	7.4	30.5	30.7	33.1	32.7
6	8.5	37.5	38.7	41.1	41.7
37	5.7	19.0	20.2	21.1	21.2
42	5.4	24.0	25.7	24.6	25.2
48	6.2	35.0	36.2	38.1	38.7

TABLE 10.—*Degree of dispersion*—Continued

USING ELECTRICAL STIRRER

Soil No.	Solid matter dispersed in—						
	0 minutes	9 minutes	15 minutes	30 minutes	45 minutes	60 minutes	75 minutes
2	7.4	28.4	30.7	32.6	33.5	33.9	34.0
6	8.5	38.2	40.1	41.1	42.1	42.3	42.9
37	5.7	17.3	19.4	22.8	24.1	26.2	26.1
42	5.4	21.1	25.9	28.0	28.6	30.0	30.2
48	6.2	32.3	34.9	37.1	38.9	39.7	39.7

The method of dispersing with an electrical stirrer is thus seen to be far superior to the methods of rubbing in mortar or shaking in an end-over-end shaker. Dispersing in an electrical stirrer for 45 minutes was found to be equivalent in efficiency to shaking in an end-over-end shaker for 24 hours. Rubbing in a mortar gave the least efficient dispersion of the three methods studied. In subsequent work, therefore, the electrical stirrer was used. The figures also show that maximum dispersion was obtained by this method after stirring for 60 minutes. The relative efficiency of these various devices is shown graphically in Figure 10, which gives in addition to the individual dispersion curves, a composite average curve.

CHEMICAL ASPECT

Various chemicals tried, supplying a hydroxyl ion to stabilize the dispersed colloidal particles, included ammonia (1 per cent solution) potassium hydroxide and sodium hydroxide (5 cubic centimeters normal solution per liter of suspension), and sodium carbonate (0.2 per cent). Table 11 gives the magnitude of dispersion obtained with the aid of these deflocculents. The mechanical means employed was always the same, that is, stirring in an electrical stirrer for 60 minutes. This method gave the maximum dispersion in the first part of the study. Bouyoucos' hydrometer was used to determine the degree of dispersion in the same manner as described in the foregoing.

TABLE 11.—*Effect of various chemical treatments on the degree of dispersion*

[Results expressed in grams per liter of solid matter in suspension after 15 minutes]

Soil No.	Solid matter in suspension when using—				
	H_2O	NH_4OH	KOH	NaOH	Na_2CO_3
	Grams	*Grams*	*Grams*	*Grams*	*Grams*
2	34.0	27.9	34.0	36.4	38.5
6	43.7	37.2	42.5	44.9	45.1
37	10.4	25.6	26.0	28.6	31.7
42	25.6	28.3	30.0	32.8	34.4
48	38.8	38.4	39.5	41.3	42.3

Sodium carbonate gave the best dispersion in every instance. Similar results were obtained by Joseph and Snow (*20, p. 119*), working with heavy Sudan soils. Sodium hydroxide was better than potassium hydroxide in every instance. The behavior of the two alkaline soils, Nos. 2 and 6, is of interest. They dispersed much better in distilled water than in ammonia, and even the use of caustic

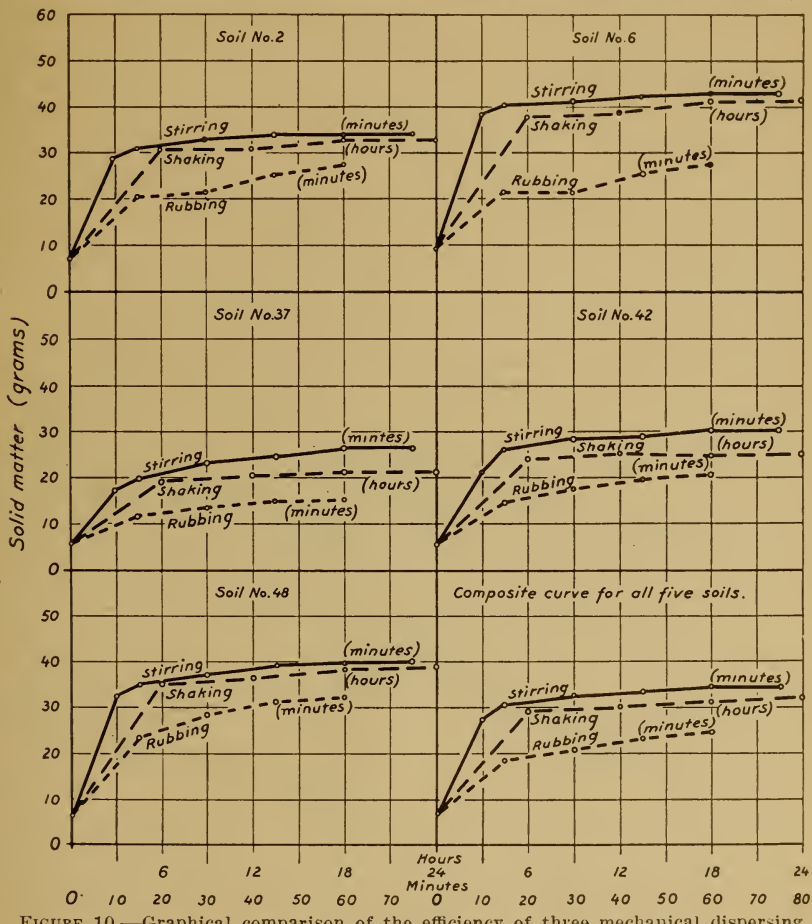

FIGURE 10.—Graphical comparison of the efficiency of three mechanical dispersing devices

potash did not increase the dispersion obtained in water alone. In the case of soil No. 48 (acid), the use of ammonia did not increase the dispersion over that obtained with water.[3]

The relative efficiency of the various chemicals is shown graphically in Figure 11 for the different soils, as well as the composite curve for the averages of all soils.

The effect of increasing the concentration of a deflocculent (potassium hydroxide) was studied on a typical Hawaii clay. The

[3] Since these determinations were carried out, other investigators have shown that lithium carbonate causes an even better dispersion than does sodium carbonate.

amounts of normal potassium hydroxide used were 5, 10, 15, 20, and 25 cubic centimeters. The concentrations were determined after 0, 15, 30, 45, 60, and 75 minutes of settling time. Corrections were made for the increase in density of the dispersing medium due to the potassium hydroxide. Table 12 shows the results obtained.

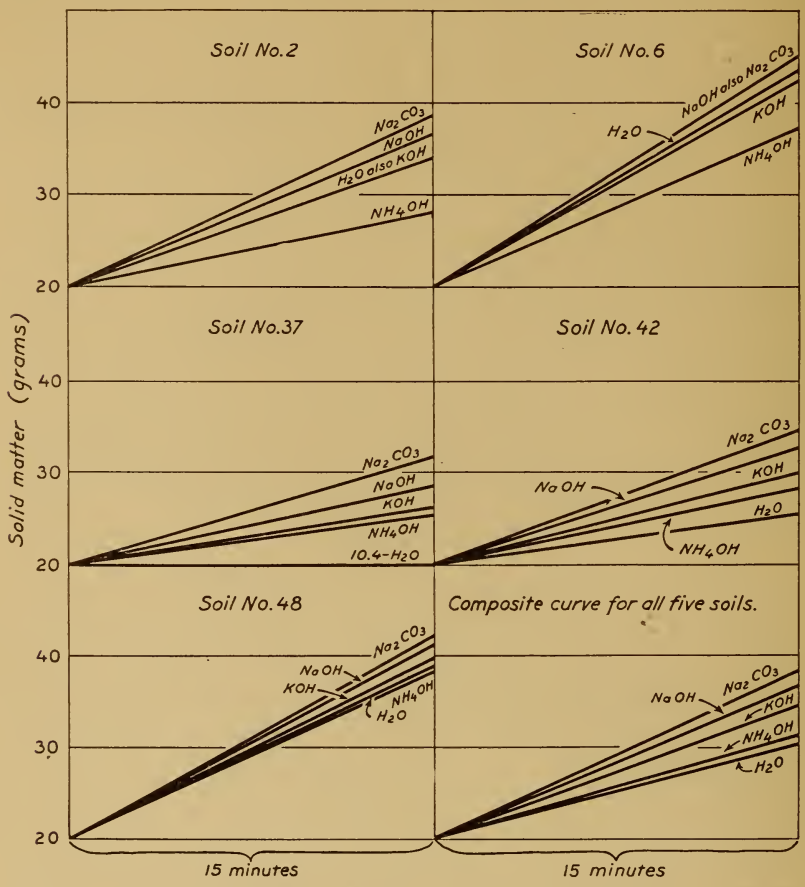

FIGURE 11.—Graphical comparison of the efficiency of various chemicals in dispersion

TABLE 12.—*Effect of increase in concentration of alkali (KOH) upon degree of dispersion of a typical Hawaii clay*

[Results expressed in grams per liter of solid matter in suspension]

Amount of KOH, cubic centimeters	Solid matter in suspension after settling for—					
	0 minutes	15 minutes	30 minutes	45 minutes	60 minutes	75 minutes
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
5	40.3	28.3	26.3	25.3	24.3	22.8
10	39.9	27.4	26.4	25.4	24.9	23.4
15	39.5	28.0	26.5	25.5	24.0	23.5
20	39.1	28.6	26.6	25.1	24.6	23.6
25	39.7	28.2	26.7	25.2	24.2	22.7

Table 12 shows that increase in concentration of hydroxyl ions does not increase the degree of dispersion. Charlton (*12*, *p. 9*) observed similar phenomenon, noting that "increasing the concentration of ammonia does not increase the dispersion of clay."

The use of hydrogen peroxide is recommended by some investigators to oxidize the organic matter present, which has a flocculating effect on the fine material. The use of hydrochloric acid is also advocated to remove certain bases, such as calcium, which has a similar effect. Fifth-normal and twentieth-normal hydrochloric acid have been used by various workers to remove calcium. The objection to the use of stronger concentration has been repeatedly raised, due to the solvent effect of the acid upon the iron and aluminum compounds.

In order to learn whether the organic matter present interfered with the work of obtaining perfect dispersion, in view of the large amount of humus contained in many Hawaii soils, the degree of dispersion was determined after the organic matter had been treated with superoxol (30 per cent solution of hydrogen peroxide). The flocculating effect of calcium in the dispersion was also determined by removing the calcium with cold hydrochloric acid. The two concentrations of acid used were fifth normal and twentieth normal.

The soils were treated as follows: Fifty grams of oven-dried soil was placed in a 400 cubic centimeter beaker. About 40 cubic centimeters of superoxol was added and thoroughly mixed with the soil. The mixture was then heated in a sand bath on an electrical hot plate and kept there until the evolution of oxygen was no longer noticeable. During heating, the beaker was covered with a watch glass to prevent loss by spattering. After the mixture cooled, 250 cubic centimeters of acid solution was added, and the whole was stirred and allowed to stand overnight. During the day the mixture was stirred several times. The following morning the mixture was poured into a porous filtering dish, and the acid was removed by suction. The filtrate was tested for calcium with ammonium oxalate solution. The soil was repeatedly leached with the acid solution until the filtrate gave no test for calcium. Thereupon the excess acid was removed by washing with distilled water until the filtrate gave no test for chlorides. The soil was then transferred to a dispersing cup, the alkali solution was added, and the soil was dispersed for one hour. After the usual settling period, the degree of dispersion was read by means of the hydrometer.

Table 13 shows the effect of the treatment with hydrogen peroxide and the removal of calcium by hydrochloric acid upon the degree of dispersion. Column 2 gives the degree of dispersion when neither the organic matter was affected nor the calcium removed, and the soil was dispersed with the aid of potassium hydroxide alone. Column 3 gives the dispersion with treatment by hydrogen peroxide but without removal of the calcium. Columns 4 and 5 give the dispersion with the calcium removed by fifth-normal and twentieth-normal hydrochloric acid, respectively, but without the hydrogen peroxide treatment prior to the acid treatment. Column 6 shows the degree of dispersion after both hydrogen peroxide and acid treatments. Column 7 shows the percentage loss due to superoxol treatment of the soil.

TABLE 13.—*Effect of hydrogen peroxide (superoxol) and hydrochloric acid upon dispersion as compared with dispersion by the use of KOH alone*

[Results expressed in grams per liter solid matter in suspension after 15 minutes]

Soil No.	Solid matter in suspension after treatment with—					Loss due to superoxol treatment
	KOH alone	Superoxol plus KOH[1]	N/5 HCl plus KOH	N/20 HCl plus KOH	Superoxol plus N/20 HCl plus KOH[1]	
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Per cent*
2	34.0	32.7	34.9	35.6	35.7	0.43
6	42.5	43.3	44.6	44.0	44.8	1.52
37	26.0	26.1	30.4	30.4	30.7	3.39
42	30.0	30.4	33.1	33.6	34.2	3.46
48	39.5	41.2	41.1	41.1	42.5	2.00

[1] Figures were corrected for loss due to superoxol treatment, assuming that all the loss was borne by the fraction that stayed in suspension after the settling period.

In a study of Table 13, several points are noteworthy:

Treatment with hydrogen peroxide solution apparently does not increase the degree of dispersion even in the case of soils containing from 9 to 11 per cent organic matter. A special determination of the effect of superoxol on a highly organic soil was made to supplement this table. Soil No. 9, containing 18.5 per cent organic matter, was treated in the manner described, and the dispersion was determined. In this case the soil treated with hydrogen peroxide gave a dispersion of 30.5 per cent as compared with 29.5 per cent without the treatment. According to these findings, the treatment of organic matter with hydrogen peroxide is not necessary except, perhaps, in soils containing upward of 15 per cent organic matter.

The use of acid to remove calcium is necessary to obtain maximum dispersion. On an average, 2.6 per cent more solid matter is kept in suspension in the case of acid-treated soils than in untreated soils after the dispersion has been completed.

Twentieth-normal hydrochloric acid was just as effective in the removal of calcium as was the fifth normal. As a matter of fact, of 21 soils treated in this manner, only in one instance—soil No. 77—was the twentieth-normal acid not sufficiently strong to remove all calcium. In this case fifth-normal acid was used.

These results are in good agreement with those obtained by other investigators, notably Charlton (*12*, *p. 9*), and Puri and Amin (*28*, *p. 15*), working with tropical lateritic clays in India.

ESTIMATION OF COLLOIDS BY THE WATER-VAPOR ADSORPTION METHOD

It has long been realized that certain soil properties are due largely, if not wholly, to the colloidal fraction of the soil. To such properties belong heat of wetting, base exchange, and adsorption. This fact suggests the possibility of estimating the amount of colloids by determining one of these properties in the soil and also in a representative portion of the colloidal fraction of the soil that has been extracted. The ratio of the two figures obtained would give the percentage of colloidal material in the soil.

Several assumptions had to be made that such methods would yield even approximately correct figures: (1) It had to be assumed that the extracted colloid is representative of the whole colloidal complex

of the soil; (2) that the property employed in the estimation is not altered during extraction; and (3) that the property employed in the estimation is possessed by the colloidal fraction only, or at least to an overwhelming extent. In connection with this, it was assumed that all the organic matter exhibiting adsorptivity is obtained in the colloidal fraction. Soil particles less than 2 microns in diameter were considered as colloidal.

Within recent years the power of the soil to adsorb moisture from a saturated atmosphere has been used frequently to determine the colloidal content. The method used consists in dispersing the soil in water and allowing the sand and silt fractions to settle according to Stokes' law. This gives the colloidal fraction in suspension whence the colloids are obtained by filtering or by supercentrifuging, and afterwards drying. The adsorption of water vapor is then determined for both the soil and the extracted colloid by exposing them to a saturated atmosphere of water vapor over 3.3 per cent sulphuric acid at a certain temperature for the length of time required to assure complete adsorption. From the adsorption of the soil and that of the colloidal fraction the percentage of colloids is calculated. This method was tried on a number of common, and a few unusual types of Hawaii soils, the characteristics of which are given in Tables 1, 2, 3, and 4, and in the Appendix.

In order to obtain a representative part of the colloidal phase of the soils—which has the same power of adsorption it has in the soil—50-gram aliquots were repeatedly shaken with distilled water in an end-over-end shaker for four hours and allowed to settle according to Stokes' law for the length of time required to leave only particles smaller than 0.002 millimeter in suspension. The suspension was then siphoned off, the collected fractions were mixed, and the colloids in suspension were passed through Pasteur-Chamberland filters. The separated colloids were dried at room temperature and passed through a 60-mesh screen. A fairly large amount of soil colloids was obtained, as is shown in Table 14.

TABLE 14.—*Percentage of total colloids extracted by three successive dispersions*

Soil No.	Colloids extracted (*a*)	Total colloids (*b*)	Proportion of total colloids to colloids extracted (*a*/*b*)	Soil No.	Colloids extracted (*a*)	Total colloids (*b*)	Proportion of total colloids to colloids extracted (*a*/*b*)
	Per cent	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*
2	40.82	51.5	79.2	42	7.16	32.5	22.0
6	50.16	66.6	75.3	48	10.04	30.1	33.4
9	8.12	27.0	30.1	49	2.76	21.3	13.0
12	3.64	15.0	24.2	56	22.76	48.0	47.4
21	9.36	23.9	39.2	57	23.24	49.1	47.3
23	1.88	15.5	12.1	65	15.88	35.1	45.2
31	9.60	49.3	19.5	66	12.14	30.6	39.7
33	.96	17.0	5.6	76	9.94	25.8	38.5
37	4.62	23.1	20.0	77	2.58	28.1	9.2

This method of procedure permitted presumably little change in the adsorptivity of the soil colloids during treatment.

Although all the soils, with the exception of soil No. 69, contained only a small amount of soluble salts, the samples for determination were washed with water to prevent the salts from influencing the

water-vapor adsorption. The adsorption of water vapor was determined in accordance with the findings of Middleton (*26, p. 455*), who noted the effect of the various factors upon the adsorption entering into this determination. Two to three grams of soil or colloid was placed in shallow aluminum dishes, and these in turn were placed in a desiccator over 3.3 per cent by weight of sulphuric acid. From 20 to 28 samples were used at the same time, and 100 cubic centimeters of sulphuric acid. The adsorption of the colloids and of their corresponding soils was always determined together. The desiccator was evacuated by a vacuum pump to about 28.5 inches mercury—about 50 millimeters absolute pressure—placed in a thermostat which was regulated to 30° C., and kept there for six days. At the end of that time adsorption was considered as complete. The dishes were immediately covered, weighed, and dried at 105° for 18 hours, and then weighed again. Table 15 gives the adsorptivities obtained and the percentage of colloids calculated therefrom. The results are shown graphically in Figure 12.

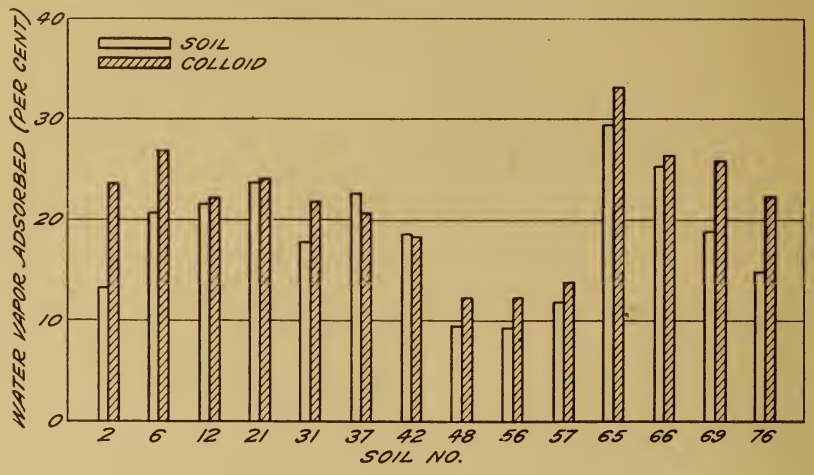

FIGURE 12.—Water vapor adsorbed by soil and extracted colloid

TABLE 15.—*Water vapor adsorption in Hawaii soils and colloids as a measure of colloidal content*

Soil No.	Adsorption per gram of soil (*a*)	Adsorption per gram of colloid (*b*)	Computed percentage of colloids in soil $\frac{a}{b}\times 100$	Amount of colloids by pipette method	Soil No.	Adsorption per gram of soil (*a*)	Adsorption per gram of colloid (*b*)	Computed percentage of colloids in soil $\frac{a}{b}\times 100$	Amount of colloids by pipette method
	Gram	*Gram*	*Per cent*	*Per cent*		*Gram*	*Gram*	*Per cent*	*Per cent*
2	0.133	0.236	56.4	51.5	56	0.093	0.124	75.0	48.0
6	.208	.271	76.7	66.6	57	.120	.138	87.0	49.1
12	.216	.221	97.7	15.0	65	.296	.331	89.4	35.1
21	.237	.240	98.7	23.9	66	.256	.266	96.2	30.6
31	.178	.219	81.3	49.3	69	.188	.260	72.3	48.9
37	.226	.208	108.6	23.1	76	.148	.223	66.4	25.8
42	.186	.183	101.6	32.5					
48	.097	.122	79.5	30.1	Average	.184	.217	----------	----------

Columns 2 and 3 give the water vapor adsorbed, expressed on a dry basis, by soils and colloids, respectively. Column 4 gives the ratio adsorption per gram of soil to adsorption per gram of colloid multiplied by 100, or the computed percentage of colloids. For the sake of comparison, the percentage of colloids as determined in the mechanical analysis is given in column 5.

The magnitude of adsorption varied considerably, both in soils and in colloids. In soils the adsorption ranged between 10 and 30 per cent in round numbers, with an average of 18.4 per cent; whereas the adsorption of the colloids ranged between 12 and 33 per cent, with an average of 21.7 per cent. In several cases the percentage of adsorption of soil was nearly equal to, or even greater than, the percentage of adsorption of the corresponding colloid. On the whole, the average adsorption of the 14 soils given in Table 15 is less than the average adsorption of mainland soil colloids, which was found to be about 30 per cent in certain types of soil. One of the reasons for this difference, other than for the difference in chemical composition, may be due to the fact that in this investigation everything failing to settle out from suspension at the 0.002-millimeter limit according to Stokes' law was considered to be colloid; whereas in the case of the soils of the mainland the upper limit of the colloidal particle was about 0.0003 millimeter. The average amount of colloid extracted from the above-mentioned 14 soils was around 13 grams per 100 grams of soil, comprising about 42 per cent of the total colloids present as determined by the mechanical analysis. Obviously, a constant "adsorption per gram of colloid" factor could not be applied in this case to all the soils since the fluctuations in value were rather considerable. The percentage of colloids computed from the adsorptivities gives excessive results, in two instances the figure being above 100. Only in two instances is there a semblance of agreement with the colloids estimated in the mechanical analysis.

In discussing these very divergent results, certain relationships which were brought out earlier in this bulletin (pp. 23, 25) are called to the reader's attention. It was pointed out that the amount and distribution of organic matter and the chemical composition of the inorganic phase in the various soil fractions seem to be of such nature in many Hawaii soils as to preclude the use of the water-vapor adsorption method for computing the percentage of colloids. The figures obtained indicate that the above-referred-to assumptions made in connection with this method are not permissible for many Hawaii soil types containing high percentages of organic matter. The figures given in Table 8 indicate that a large part of the organic matter may be present in the silt, and even in the sand fractions, either as separate particles or as aggregates resisting dispersion, exhibiting high adsorptive properties. Furthermore, it is an established fact that particles show colloidal properties, even to a lesser extent perhaps, long before the arbitrary limit made for colloids or clay is reached.

Davis (*14, p. 276*) finds that the dispersion of soils in the course of mechanical analysis may be so incomplete that the silt fraction will contain 25 to 97 per cent colloids in the form of aggregates, and that even the sand fraction may contain 2 to 25 per cent colloids in the

undispersed state. If, therefore, the larger part of of the undispersed colloid happens to be mainly of an organic nature having a much higher adsorptivity (15 to 35 per cent higher) than that of the dispersed colloid, which on the other hand happens to be chiefly of an inorganic nature having a much lower adsorptivity, then the phenomenon observed in Hawaii soils may be easily explained.

Other investigators have made similar observations. Bennett and Allison (*4, p. 25*), working with Cuba soils, state that the colloidal content, as determined by the water-vapor adsorption method, frequently runs 10 or 15 per cent in excess of the actual clay content, "probably because of exceptional physical properties of the soil material." This fact is all the more remarkable because the clay fraction of mechanical analysis has an upper limit of 0.005-millimeter diameter, whereas the upper limit of colloids, as interpreted in the water-vapor adsorption method, is much less—probably below 0.001 millimeter. Therefore, the percentage of colloids should be considerably less than that of clay. Furthermore, the organic matter of the Cuba soils referred to is very low in comparison with Hawaii soils, most of them ranging between 1 and 5 per cent. Much larger discrepancies may logically be expected with soils having two or three times this amount of organic matter.

Steele (*33, p. 31*), referring to the colloids of Ohio soil profiles, remarks that "there was a fairly good correlation between the Robinson, water-absorption, and heat-of-wetting methods, except in soils high in organic matter."

Alway (*2, p. 246*) believes that "it does not appear yet satisfactorily established that the ability of soils to absorb water vapor is a reliable measure of their colloid content."

Joseph and Snow (*20, p. 119*), working with heavy Sudan soils, state that—

> There is no connection between the proportion of very fine material (*e. g.* below 0.5μ) and other important soil properties. The proportion of the very fine material determined in this way [viz, sedimentation] would not, therefore, afford any indication of the "colloid" properties of the soil.

The moisture-adsorbing capacity of two different fractions of the colloidal phase was determined in the case of two soils and compared with that of the soil from which they were isolated. One fraction was that part of the colloidal phase which could be isolated from suspension by means of supercentrifuging at the rate of 36,000 revolutions per minute, whereas the other part was that fraction which could not be separated from suspension by this treatment, but had to be filtered through Pasteur-Chamberland filters and concentrated on the surface of the filtering tubes. This latter fraction is sometimes referred to as "ultra-clay." This ultra-clay amounted sometimes to 1 to 1.5 per cent of the soil. Table 16 shows the hygroscopicity of these two fractions as compared with that of the parent soil in the case of two highly organic, highly hygroscopic soils.

In both instances the fine fraction of the colloidal phase or ultra-clay showed less adsorption than the coarse-colloidal fraction, indicating the probable presence of the highly adsorptive organic material in larger amounts in the coarse-colloidal fraction and in smaller amounts in the fine-colloidal fraction. Moreover, in the case of soil No. 12 the adsorptivity of the original soil is higher than that of

either colloidal fraction, indicating a higher adsorptivity of the noncolloidal fraction in this soil than in the colloidal fraction.

TABLE 16.—*Hygroscopicity of coarse and fine fractions of the colloidal material as compared with that of the original soil*

Soil No.	Organic matter	Water vapor adsorbed per gram of material		
		Original soil	Colloids	
			Coarse fraction	Fine fraction (ultra-clay)
	Per cent	*Gram*	*Gram*	*Gram*
12	15.75	0.395	0.388	0.324
21	13.36	.350	.389	.352

In conclusion, therefore, it seems inadvisable to attempt to translate physical properties into particle size with soils of high organic content, such as are found in humid tropical regions. The writer is of the opinion that the determination of the various fractions in the mechanical analysis and the determination of the magnitude of a significant physical property, such as water-vapor adsorption carried out on a soil, will adequately describe the quantitative colloidal properties of that soil, even though a part of the colloidal property be due, for some reason, to the fine silt fraction for instance. If to these determinations is added the chemical analysis of the clay fraction, an approximate qualitative picture may be obtained of the fraction chiefly responsible for these colloidal properties. It appears, however, that with a highly heterogeneous substance, such as soil, possessing a number of compounds both organic and inorganic in widely varying proportions not only in different soils but sometimes in the different fractions of the same soil, the expression of a certain physical property in terms of particle size may sometimes become misleading.

COMPARISON OF THE HYDROMETER AND A MODIFIED PIPETTE METHOD OF MECHANICAL ANALYSIS

Bouyoucos (*5*, *6*, *7*) proposed the use of a hydrometer for measuring soil-suspension concentrations. In an early publication (*6*, *p. 480*) on the subject, he proposed a rapid method for the determination of the sand, silt, and colloid fraction of soil. In this method the hydrometer reading is taken of the soil suspension after 1 and 15 minutes of settling time, and from these readings the three fractions are computed. The author pointed out that in this method the colloid fraction includes a part of the fine silt fraction. In his subsequent article (*7*, *p. 235*), Bouyoucos proposed the use of the hydrometer for a detailed mechanical analysis in which any number of class divisions might be made. Hydrometer readings are taken at different intervals according to Stokes' law of settling particles, and from the readings the particular fraction in question is calculated. The method and its different modifications are too well known to need describing here in detail, hence only a résumé is given.

The method consists in dispersing 50 or 100 grams of soil by an electrical stirring apparatus in a specially constructed metal cup. The dispersed soil is made up to a definite volume with water in a glass cylinder, and after the required settling time the density of the soil suspension is read by means of a hydrometer constructed for the purpose. The hydrometer is calibrated to give correct readings (grams of solid matter per liter of water) at 67° F. Under or above this temperature a necessary correction is made, that is, 0.35 is added to or deducted from the reading for each degree above or under 67°. The corrected reading divided by the weight of soil used gives the percentage of the fraction in question. The results by this method are said to check with those of the heat-of-wetting method of determining soil colloids.

In the study of Hawaii soil colloids in the station laboratory, this method was used as a routine analysis to classify a larger number of soil samples taken from the different parts of the four principal islands. Because of this fact it became desirable to determine (1) how closely the rapid method proposed by Bouyoucos (consisting of two readings only) agrees with the pipette method, and (2) how closely a detailed mechanical analysis, as performed with the aid of a hydrometer, compares with a pipette method of analysis.

In checking the rapid method of hydrometer analysis no consideration was taken of the rather wide variations in specific gravity of Hawaii soils. The readings were taken always after settling for 1 and 15 minutes, regardless of the specific gravity of the soil in question. That this sometimes introduces appreciable error is known from the fact that the specific gravity of Hawaii soils was found to range from 2.17 to 3.36. In the detailed hydrometer analysis, however, the correct settling period was calculated from the specific gravity of the soil and from the viscosity of water at the temperature of the measurement. The depth in the hydrometer method was considered as 32.5 centimeters, in accordance with Bouyoucos' calculations, the Bouyoucos hydrometer cylinder used registering the average density of a soil-suspension column 32.5 centimeters high.

The method with which the hydrometer method was compared in this investigation had the same principle as the original pipette method of Robinson (*30, p. 311*), that is, sampling a soil suspension at a constant depth at calculated intervals and determining the concentration. It differs from it in that sampling was not done by means of a pipette, but by a stopcock fitted in the wall of the cylinder. In this method the samples were taken from a 100-millimeter depth, corresponding to about an 8-hour settling period for the clay fraction. The exact time of settling was calculated from the specific gravity of the soil and the temperature. Puri, Amin (*28, p. 5*), and Robinson (*30, p. 318*) show that closely agreeing figures were obtained from sampling at different depths at the corresponding calculated settling time. Temperature conditions were observed by placing the soil suspensions in an electrically controlled thermostat, regulated at 30° C. with an accuracy of plus or minus one-half degree. The cylinders were kept in the thermostat at this temperature throughout the experiment, the door being opened only to permit taking a reading or for making a sampling.

The temperature of the outside—that is, the room—was very nearly that of the thermostat. The glass cylinder used for the modified pipette method was 45 centimeters in height, 6 centimeters in diameter, and had a 1,000 cubic centimeter capacity. At the 100-millimeter depth a glass stopcock one-fourth inch in diameter was fitted into a circular opening extending into the interior of the cylinder about one-sixteenth of an inch. Sampling was done through this stopcock instead of a pipette to avoid cumbersome operations in the thermostat.[4] At the time of sampling the first 10 drops of suspension in the stopcock were discarded. Only four samplings were taken to give the colloidal, very fine silt, fine silt, and silt fractions. The sand fraction was obtained by difference. The results are summarized in Table 17.

TABLE 17.—*Comparison of the rapid hydrometer method and the pipette method of mechanical soil analysis*

Soil No.	Mechanical analysis by hydrometer			Mechanical analysis by pipette method				
	Colloids	Silt	Sand	Colloids <(0.002 millimeter)	Very fine silt (0.002 to 0.005 millimeter)	Fine silt (0.005 to 0.01 millimeter)	Silt (0.01 to 0.02 millimeter)	Sand >(0.02 millimeter)
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2	61.	17	22	51.5	5.8	8.7	8.8	25.2
6	80	13	7	66.6	7.4	6.4	3.9	15.7
9	30	40	30	27.0	16.0	10.5	12.5	34.0
12	23	16	61	15.0	11.0	7.0	12.0	55.0
15	25	17	58	9.5	8.6	5.4	8.0	68.5
17	19	21	60	11.8	9.0	2.5	7.2	69.5
21	44	24	32	23.9	15.4	12.1	10.1	38.5
23	38	30	32	15.5	12.0	12.0	15.0	45.5
31	72	17	11	49.4	15.6	11.6	6.9	16.5
33	30	33	37	17.0	5.0	9.0	15.0	54.0
37	39	17	44	23.1	16.2	10.7	9.1	40.9
42	53	17	30	32.5	16.8	8.7	8.0	34.0
48	68	31	1	30.1	23.4	20.6	14.7	11.2
49	32	22	46	21.3	7.2	6.0	9.8	55.7
56	76	21	3	48.0	18.2	11.8	9.2	12.8
57	76	21	3	49.1	14.4	10.9	9.4	16.2
65	48	31	21	35.1	7.7	11.6	18.9	26.7
66	44	20	36	30.6	8.7	7.6	10.9	42.2
69	70	10	20	48.9	14.9	13.6	8.4	14.2
76	44	26	30	25.8	15.8	8.6	21.6	28.2
77	43	22	35	28.1	5.2	6.8	6.9	53.0
Average	48.3	22.2	29.5	31.4	12.1	9.6	10.8	36.1

Table 17 shows a fair agreement between the two methods. Taking the over-all averages it is seen that the colloids indicated by the hydrometer method included all the very fine silt fraction and half the fine silt fraction of the pipette method. Since the sand fraction was obtained in both instances by subtraction, it is not strictly comparable, yet the disparity exhibited is not great.

The detailed hydrometer method was also compared with the pipette method. Only the colloidal and the three silt fractions were determined, the sand fraction having been obtained by subtraction. The data obtained are given in Table 18.

[4] This method of sampling was checked against the original method of sampling by means of a pipette, and the agreement between them was found to be so close as to permit duplicating the results with considerable accuracy.

TABLE 18.—*Comparison of the detailed hydrometer method and the pipette method of mechanical soil analysis*

Soil No.	Method	Mechanical analysis				
		Colloids <(0.002 millimeter)	Very fine silt (0.005–0.002 millimeter)	Fine silt (0.01–0.005 millimeter)	Silt (0.02–0.01 millimeter)	Sand >(0.02 millimeter)
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2	Hydrometer	49.3	8.0	7.0	7.0	28.7
	Pipette	51.5	5.8	8.7	8.8	25.2
6	Hydrometer	63.3	12.0	6.0	5.0	13.7
	Pipette	66.6	7.4	6.4	3.9	15.7
37	Hydrometer	23.3	12.0	10.0	8.0	46.7
	Pipette	23.1	16.2	10.7	9.1	40.9
42	Hydrometer	28.3	18.0	10.0	6.0	37.7
	Pipette	32.5	16.8	8.7	8.0	34.0
48	Hydrometer	30.0	18.0	17.0	23.0	12.0
	Pipette	30.1	23.4	20.6	14.7	11.2
64	Hydrometer	59.9				
	Pipette	59.6				

The figures given in Table 18 show that the agreement in this case is much closer than in the case of the rapid hydrometer method. The over-all averages for the five soils, Nos. 2, 6, 37, 42, and 48, compare for the different fractions as follows: Colloids, 38.8 and 40.7 per cent; very fine silt, 13.6 and 13.9 per cent; fine silt, 10 and 11 per cent; silt, 9.8 and 8.9 per cent; and sand, 27.8 and 25.4 per cent. In each case the first figure given was by the hydrometer method and the second by the pipette method.

SUMMARY

Data relative to the origin, formation, and composition of tropical Hawaii soils are given.

Physical characteristics of 21 soils which were selected for the investigation are described.

Mechanical analyses of a few typical soils, with special reference to the fine fraction, are given. Variations in apparent and real specific gravities are pointed out. Hygroscopic and capillary moisture, moisture-holding capacity, and moisture equivalent of these soils were determined and correlated with the texture and organic-matter content. The amount and distribution of organic matter is a determining factor in moisture relationships.

A considerable portion of the organic material is often in the noncolloidal fraction. With soils the organic content of which is small, the textural conditions and the chemical composition are the determining factors. Sometimes large differences exist in the silica sesquioxide ratio of the different fractions in any one soil.

Experimental results on the dispersing qualities of typical Hawaii soils are given. For mechanical study the electrical stirrer was found to be far superior to either of the methods of shaking or rubbing. For chemical treatment prior to dispersion it was found that in most cases cold twentieth-normal hydrochloric acid is satisfactory for the removal of calcium, that the destruction of organic matter with hydrogen peroxide is not necessary, and that sodium carbonate is the best agent to aid deflocculation.

The percentage of colloids was determined by the water-vapor adsorption method. The figures obtained were too high, sometimes being abnormally in excess of the figures indicated by the pipette or the hydrometer method. This was chiefly due to the amount and distribution of the organic material and also to disparity in the chemical composition of the inorganic phase.

The pipette and hydrometer methods of mechanical analysis are compared. The detailed hydrometer method, which takes into account the specific gravity and temperature, gives a good agreement with the pipette method. The rapid hydrometer method, while showing greater disagreement with the pipette method than does the detailed hydrometer method, is sufficiently useful for the routine classification of soils.

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APPENDIX

PHYSICAL CHARACTERISTICS OF SOME TYPICAL AND UNUSUAL HAWAII SOILS

Soil No.	District and island	Vegetation	Elevation	Annual rainfall	Mean temperature	Depth	Soil class [1]	Color	Organic matter [2]	pH [3]	Hygroscopic moisture [4]	Mechanical analysis [5]			Soluble salts [6]
												Sand	Silt	Clay	
			Feet	*Inches*	°*F.*	*Inches*			*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	Olaa, Hawaii	Barren	1,500	200	73	Subsoil.	Sandy loam	Brown	8.73	5.59	20.1	67	16	17	0.182
2	Lanikai, Oahu	Grass	0	60	73	0–10	Clay	Light brown	3.94	8.23	6.1	22	17	61	.127
3	Koko Head, Oahu	*Panicum* sp	20	40	75	0–12	do	Gray	10.65	8.10	8.0	21	18	61	.177
4	do	Barren	20	40	75	0–8	do	do	4.37	8.35	8.8	8	14	78	.112
5	Wailupe, Oahu	Sorghum	15	40	75	0–12	do	do	6.08	8.17	7.9	11	24	65	.400
6	Salt Lake Crater, Oahu	Abandoned cane field.	350	60	75	0–12	do	do	3.89	8.73	10.8	7	13	80	.110
7	Waikee, Hawaii	Corn and pasture	3,500	50	65	0–12	Clay loam	Brownish gray	8.63	7.87	10.8	40	32	28	.182
8	Wahiawa, Oahu	Native	1,000	60	71	0–12	Clay	Red	8.25	6.80	4.5	13	14	73	.104
9	Peninsula, Oahu	Barren	0	40	75	Subsoil.	Clay loam	Light gray	18.52	4.80	10.0	30	40	30	1.556
10	Olaa, Hawaii	Sugarcane	1,500	200	72	0–12	Sandy clay loam	Brown	12.42	6.67	18.0	64	16	20	.187
11	do	do	1,500	200	72	12–24	Sandy clay	do	5.04	5.89	24.3	52	14	34	------
12	do	do	1,500	200	72	0–12	Sandy clay loam	Light brown	15.75	5.87	14.1	61	16	23	.088
13	do	do	1,500	200	72	12–24	Sandy loam	Brown	10.52	5.76	17.8	61	39	0	------
14	do	do	1,500	200	72	12–24	Clay	do	6.87	5.85	17.9	49	17	34	------
15	do	do	1,000	200	72	0–10	Sandy clay loam	Gray	25.52	5.77	14.0	58	17	25	.318
16	Glenwood, Hawaii	Grass	2,500	+200	64	0–24	do	Brown	11.71	5.71	13.1	54	25	21	.168
17	Volcano, Hawaii	Fern forest	4,000	130	64	0–12	Sandy loam	Gray	8.49	6.50	3.1	60	21	19	.133
18	do	Volcanic ash	4,000	130	64	0–2	do	Light gray	0	7.25	0	62	24	14	.011
20	Pahala, Hawaii	Sugarcane	1,700	50	73	0–12	Clay	Reddish brown	5.27	6.40	11.5	44	24	32	.086
21	Kona, Hawaii	Coffee	1,550	80	71	0–12	do	Brown	13.36	6.55	15.4	32	24	44	.110
22	do	do	1,550	80	71	12–24	Sandy clay loam	do	8.37	6.15	23.0	57	17	26	------
23	do	do	1,475	80	71	0–8	Clay	Grayish brown	12.45	7.17	15.8	32	30	38	.128
24	do	do	1,475	80	71	12–18	Clay loam	Brownish gray	8.33	6.58	18.6	49	22	29	------
25	do	do	1,500	70	71	12–18	Sandy clay loam	Light brown	6.30	5.81	24.4	53	19	28	------
26	do	Barren	1,400	90	71	12–18	Silt loam	Red	4.61	5.13	11.4	24	76	0	------
27	Kohala, Hawaii	Sugarcane	600	40	73	0–12	Clay	Light brown	7.12	7.33	7.4	15	18	67	.080
28	do	do	600	40	73	12–24	do	Brown	5.81	7.02	7.8	7	13	80	------
29	do	Barren	300	50	73	72–84	do	Yellowish brown	5.67	4.75	16.2	17	15	68	------
30	do	Pasture	1,500	65	73	0–2	Clay loam	Reddish brown	0.63	6.43	17.2	46	31	23	------
31	do	Pineapples	750	60	73	0–12	Clay	Brown	8.15	7.40	7.4	11	17	72	.119
32	do	do	1,950	60	73	0–12	Sandy clay loam	do	8.37	7.00	11.3	51	29	20	.140
33	Waimea, Hawaii	Canna	2,700	50	65	0–12	Clay loam	do	10.95	6.70	15.7	37	33	30	.085

See footnotes at end of table.

PHYSICAL CHARACTERISTICS OF SOME TYPICAL AND UNUSUAL HAWAII SOILS—Continued

Soil No.	District and island	Vegetation	Elevation	Annual rainfall	Mean temperature	Depth	Soil class [1]	Color	Organic matter [2]	pH [3]	Hygroscopic moisture [4]	Mechanical analysis [5]			Soluble salts [6]
												Sand	Silt	Clay	
			Feet	*Inches*	°*F.*	*Inches*			*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
34	Waimea, Hawaii	Canna	2,700	50	65	16–20	Clay loam	Brown	5.63	6.77	15.0	44	32	24	------
35	Ahualoa Homesteads, Hawaii.	Pasture	2,000	90	72	0–12	Sandy clay loam	do	12.95	6.62	14.8	64	13	23	0.104
36	do	do	2,000	90	72	12–24	Sandy loam	do	7.03	5.90	22.6	77	23	0	------
37	Honokaa, Hawaii	Sugarcane	1,400	80	74	0–12	Clay	Light brown	11.56	6.36	13.9	44	17	39	.089
38	do	do	1,400	80	74	12–24	Sandy clay loam	Brown	2.50	5.88	14.7	63	16	21	------
39	do	do	300	60	74	0–12	Clay	do	4.40	6.28	8.8	40	18	42	.077
40	do	do	300	60	74	12–24	Sandy clay loam	do	2.50	6.78	10.9	53	21	26	------
41	Laupahoehoe, Hawaii	Grass	0	100	74	0–8	Clay	Dark gray	10.04	7.40	4.4	35	32	33	------
42	Hakalau, Hawaii	Sugarcane	300	200	73	0–12	do	Light yellowish brown.	9.07	6.50	12.2	30	17	53	.086
43	do	do	300	200	73	12–24	Sandy clay loam	Reddish brown	5.86	5.60	21.5	72	7	21	------
44	do	do	1,250	200	73	0–12	Sandy clay	Brown	10.39	4.91	14.8	54	15	31	.094
45	do	do	1,250	200	73	12–24	Sandy clay loam	Reddish brown	4.59	5.15	16.4	69	10	21	------
46	Hilo, Hawaii	do	1,100	180	73	60–72	Sandy loam	do	6.85	5.48	17.3	64	36	0	.092
47	do	do	1,250	180	73	48–60	Silt loam	do	5.35	5.70	8.5	42	58	0	.114
48	Hamakuapoko, Maui	Corn	2,000	50	73	0–12	Clay	Brownish red	6.67	5.97	5.5	1	31	68	.082
49	do	do	2,000	50	73	12–24	do	do	2.34	5.77	21.1	46	22	32	.025
50	Hana, Maui	Sugarcane	1,000	90	75	0–12	Sandy clay loam	Brown	6.73	------	18.4	56	24	20	.133
53	do	Pasture	250	100	75	12–16	Clay	do	4.29	6.42	9.4	26	22	52	.047
54	Haiku, Maui	Pineapples	900	70	73	0–12	do	Light grayish brown.	3.60	6.51	3.4	0	33	67	.079
55	do	do	900	70	73	12–20	do	Reddish brown	6.93	5.50	6.8	30	13	57	.041
56	do	do	1,250	80	73	0–12	do	Light brown	7.10	4.75	3.8	3	21	76	.084
57	do	do	1,250	80	73	12–20	do	Brown	6.27	5.03	3.1	3	21	76	.035
58	do	Abandoned pineapple field.	1,200	80	73	0–12	do	Grayish brown	6.45	7.22	5.1	9	24	67	.098
59	do	do	1,200	80	73	12–18	do	Dark brown	2.98	6.30	3.8	7	22	71	.039
60	Hamakuapoko, Maui	Pineapples	2,400	50	73	0–12	do	Brown	4.50	7.40	11.1	49	21	30	.051
61	do	do	2,400	50	73	24–28	Sandy clay loam	Dark brown	4.50	6.33	10.8	51	21	28	.050
62	Waiako, Maui	Diversified	2,600	65	73	0–12	do	Brown	7.47	7.72	11.7	50	27	23	.083
63	do	do	2,600	65	73	12–22	Clay	do	6.50	7.65	16.3	41	25	34	.071
64	Maui Agricultural Co., Maui.	Barren	600	60	73	0–12	do	Brownish red	3.27	7.60	4.1	16	24	60	.044
65	Honokohau, Maui	do	100	40	77	Subsoil.	do	Yellow	5.09	7.42	15.5	21	31	48	.206
66	do	do	100	40	77	Many feet.	do	Light red	2.32	7.25	9.9	36	20	44	.175
67	do	do	30	40	77	Deep.	do	Yellow	------	7.28	------	------	------	------	------
69	Lahaina, Maui	do	0	25	77	0–12	do	Light gray	1.22	7.77	5.2	20	10	70	.800

70	Wailuku, Maui	Sugarcane	60	40	76	0-6	do	Light yellowish gray.		7.95						
71	do	do	60	40	76	12-22	do	Brownish gray	1.90	7.88	4.8	28	30	42	.069
72	do	do	60	40	76	14-16	do	Brown	2.99	6.48	4.7	17	21	62	.044
73	Kapaa, Kauai	do	50	60	77	12-24	do	Reddish brown	4.42	7.00	4.2	1	16	82	.033
74	do	do	100	60	77	12-24	do	Brown	7.38	6.87	4.2	8	22	70	.045
75	Kealia, Kauai	do	400	60	77	12-18	do	do	8.95	5.31	4.9	30	5	65	.027
76	do	do	15	60	77	0-4	do	Gray	7.70	7.72	5.8	30	26	44	.089
77	do	do	15	60	77	12-24	do	Brownish gray	1.91	7.74	5.3	35	22	43	.082
78	Kilauea, Kauai	do	300	100	73	0-10	do	Light gray	7.84	6.73	3.3	16	15	69	.060
79	do	do	300	100	73	12-16	do	Light brown	7.30	6.65	4.2	16	10	74	.060
80	do	do	300	100	73	0-10	do	do	9.72	5.98	3.8	18	16	66	.068
81	do	do	300	100	73	12-20	do	Brown	7.97	5.02	4.6	22	8	70	.051
82	do	do	150	100	73	0-14	do	do	9.28	7.48	5.0	16	13	71	.117

[1] Soil class, U. S. Department of Agriculture Bureau of Chemistry and Soils' classification into 10 main groups, as described by Davis and Bennett (*15*).
[2] Percentage of organic matter by Rather's method "B", as described by Rather (*29*).
[3] Soil reaction electrometrically using quinhydrone electrode.
[4] Hygroscopic moisture by air drying to constant weight (3 to 4 days at 28° to 32° C.); then oven drying at 110° for 18 hours.
[5] Mechanical analysis by Bouyoucos' hydrometer method, as described by Bouyoucos (*6*).
[6] Per cent soluble salts by measuring electrolytic resistance of a 1 : 5 water extract.

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